DOCUMENT RESUME

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TITLE	Electronic Principles V, 7-9. Military Curriculum Materials for Vocational and Technical Education.
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SPONS AGENCY	Department of Education, Washington, DC.
PUB DATE	75
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IDENTIFIERS	Military Curriculum Project; *Solid State (Electronics); *Troubleshooting

ABSTRACT

This fifth of 10 blocks of student and teacher materials for a postsecondary level course in electronic principles comprises one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. Prerequisites are the previous blocks. This block on solid state power supplies and amplifiers contains eight modules covering 124 hours of instruction on solid state power supply rectifiers and filters (12 hours), solid state power supply regulators (7), troubleshooting solid state power supplies (36), troubleshooting solid state power amplifiers (38), solid state wideband amplifiers (7), saturable reactors and magnetic amplifiers (5), and synchro-servo systems (7). Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include a student text; eight guidance packages containing objectives, assignments, and review exercises for each module; and two handouts. A digest of the modules in the block is provided for students who need only to review the material. Designed for self- or group-paced instruction, the material can be adapted for individualized instruction. Additional print and audiovisual materials are recommended but not provided. (YLB)

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MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
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FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL
Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION

Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

NORTHEAST
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225 West State Street
Trenton, NJ 08625
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SOUTHEAST
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WESTERN
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Director
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Honolulu, HI 96822
808/948-7834

ELECTRONIC PRINCIPLES V

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Synchro-Servo Systems - Guidance Package Page 298

Developed by:

United States Air Force

Development and Review Dates:

July 1974 through November 1975

D.O.T. No.:

003.081

Occupational Area:

Electronics

Target Audiences:

Grades 13-14

Print Pages:

308

Cost:

$6.25

Availability:

Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Contents:	Type of Materials:						Instructional Design:				Type of Instruction:	
	Lesson Plans:	Programmed Text:	Student Workbook:	Handouts:	Text Materials:	Audio-Visuals:	Performance Objectives:	Tests:	Review Exercises:	Additional Materials Required:	Group Instruction:	Individualized:
			No. of pages									
Block V — *Solid State Power Supplies and Amplifiers*												
Module 34 — Solid State Power Supply Rectifiers and Filters	●		18		●	★	●	★	●	★	●	●
Module 35 — Solid State Power Supply Regulators	●		9		●	★	●	★	●	★	●	●
Module 36 — (2 parts) Troubleshooting Solid State Power Supplies	●		16	●	●	★	●	★	●	★	●	●
Module 37 — (2 parts) Troubleshooting Solid State Power Amplifiers	●		43	●	●	★	●	★	●	★	●	●
Module 38 — Troubleshooting Solid State Narrow Band Amplifiers	●		14		●		●	★	●	★	●	●
Module 39 — Solid State Wideband Amplifiers	●		28		●	★	●	★	●	★	●	●
Module 40 — Saturable Reactors and Magnetic Amplifiers	●		8		●	★	●	★	●		●	●
Module 41 — Synchro-Servo Systems	●		13		●	★	●	★	●		●	●

★ Materials are recommended but not provided.

Course Description:

This block is the fifth in a ten block course providing training in electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles and troubleshooting basic circuits. Prerequisites to this block are Blocks I, II, III and IV covering DC circuits, AC circuits, RCL circuits, and solid state principles. Block V—*Solid State Power Supplies and Amplifiers* contains eight modules covering 124 hours of instruction on power supply rectifiers and filters, power supply regulators, troubleshooting, wideband amplifiers, saturable reactors, magnetic amplifiers, and synchro-servo systems. The module topics and respective hours follow:

Module 34 — **Solid State Power Supply Rectifiers and Filters** (12 hours)
Module 35 — **Solid State Power Supply Regulators** (7 hours)
Module 36 — **Troubleshooting Solid State Power Supplies** (36 hours)
Module 37 — **Troubleshooting Solid State Power Amplifiers** (12 hours)
Module 38 — **Troubleshooting Solid State Narrow Band Amplifiers** (38 hours)
Module 39 — **Solid State Wideband Amplifiers** (7 hours)
Module 40 — **Saturable Reactors and Magnetic Amplifiers** (5 hours)
Module 41 — **Synchro-Servo Systems** (7 hours)

This block contains both teacher and student materials. Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials consist of a student text used for all the modules; eight guidance packages containing objectives, assignments, and review exercises for each module; two handouts on troubleshooting solid state power supplies and troubleshooting solid state power amplifiers; and a digest of modules 34 through 41 for students who have some background in these topics and only need to review the major points of instruction.

This material is designed for self- or group-paced instruction to be used with the remaining nine blocks. Most of the material can be adapted for individualized instruction. Some additional military manuals and commercially produced texts are recommended for reference, but are not provided. Audiovisuals suggested for use with the entire course consists of 143 video tapes which are not provided.

POI 3AQR30020-1

PLAN OF INSTRUCTION
(Technical Training)

ELECTRONIC PRINCIPLES

(Modular Self-Paced)

AIR TRAINING COMMAND

KEESLER TECHNICAL TRAINING CENTER

6 November 1975 - Effective 6 January 1976 with Class 760106

Volume 5

7-9

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DEPARTMENT OF THE AIR FORCE
USAF Sch of Applied Aerosp Sci (ATC)
Keesler Air Force Base, Mississippi 39534

PLAN OF INSTRUCTION 3AQR30020-1
6 November 1975

FOREWORD

1. PURPOSE: This publication is the plan of instruction (POI) when the pages shown on page A are bound into a single document. The POI prescribes the qualitative requirements for Course Number 3AQR30020-1, Electronic Principles (Modular Self-Paced) in terms of criterion objectives and teaching steps presented by modules of instruction and shows duration, correlation with the training standard, and support materials and guidance. When separated into modules of instruction, it becomes Part I of the lesson plan. This POI was developed under the provisions of ATCR 50-5, Instructional System Development, and ATCR 52-7, Plans of Instruction and Lesson Plans.

2. COURSE DESIGN/DESCRIPTION. The instructional design for this course is Modular Scheduling and Self-Pacing; however, this POI can also be used for Group Pacing. The course trains both non-prior service airmen personnel and selected re-enlistees for subsequent entry into the equipment oriented phase of basic courses supporting 303XX, 304XX, 307XX, 309XX and 328XX AFSCs. Technical Training includes electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles, and troubleshooting of basic circuits. Students assigned to any one course will receive training only in those modules needed to complement the training program in the equipment phase. Related training includes traffic safety, commander's calls/briefings and end of course appointments.

3. TRAINING EQUIPMENT. The number shown in parentheses after equipment listed as Training Equipment under SUPPORT MATERIALS AND GUIDANCE is the planned number of students assigned to each equipment unit.

4. REFERENCES. This plan of instruction is based on Course Training Standard KE52-3AQR30020-1, 27 June 1975 and Course Chart 3AQR30020-1, 27 June 1975.

FOR THE COMMANDER

W. H. Horne

W. H. HORNE, Colonel, USAF
Commander
Tech Tng Gp Prov, 3395th

OPR: Tech Tng Gp Prov, 3395th
DISTRIBUTION: Listed on Page A

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER V	BLOCK TITLE Solid State Power Supplies and Amplifiers

1 COURSE CONTENT	2 DURATION (Hours)
1. Solid State Power Supply Rectifiers and Filters (Module 34)	12 (9/3)
a. Given the schematic diagram for an unfiltered semiconductor half-wave rectifier, effective AC input voltage, input frequency, and a list of statements, select the statement that describes and/or identifies the current path; the output ripple frequency; the peak output voltage; the output waveform. CTS: 4h(3), 5i(5) Meas: W	(2)

(1) Describe the purpose of a rectifier.

(2) Identify schematic diagram.

(3) Explain operation in terms of

(a) current paths.

(b) input and output waveforms.

(c) input frequency and output ripple frequency.

(d) peak output voltage.

(4) Show the effect of reversing the diode.

(5) Review voltage polarities as determined by current direction.

b. Given the schematic diagram for an unfiltered semiconductor full-wave rectifier, effective AC input voltage, input frequency, and a list of statements, select the statement that describes and/or identifies the current paths; the output ripple frequency; the peak output voltage; the output waveform. CTS: 4h(3), 5i(5) Meas: W	(1)

(1) Identify schematic diagram.

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(2) Explain operation in terms of

(a) current paths.

(b) input and output waveforms.

(c) input frequency and output ripple frequency.

(d) peak output voltage.

(3) Explain the effect on output voltage due to the center tapped transformer.

(4) Show the effect of reversing the diodes and the change in output voltage polarity.

c. Given the schematic diagram for an unfiltered semiconductor bridge rectifier, effective AC input voltage, input frequency, and a list of statements, select the statement that describes and/or identifies the current paths; the output ripple frequency; the peak output voltage; the output waveform. CTS: 5j(3) Meas: W (1.5)

(1) Identify schematic diagram

(2) Explain operation in terms of

(a) current paths.

(b) input and output waveforms.

(c) input frequency and output ripple frequency.

(d) peak output voltage.

(3) Identify the output polarity with all diodes reversed.

d. Given the schematic diagram for an unfiltered semiconductor three phase rectifier (full-wave), effective AC input voltage, input frequency and a list of statements, select the statement that describes and/or identifies the current paths; the output ripple frequency; the peak output voltage; the output waveform. CTS: 5j(1) Meas: W (1.5)

(1) Identify schematic diagram

(2) Explain operation in terms of

(a) current paths.

(b) input and output waveforms.

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(c) input frequency and output ripple frequency.

(d) peak output voltage.

(3) Explain the method of changing the output polarity.

e. Given a list of statements, select the one that describes the effect of filtering on half or full-wave rectification. (2)
CTS: 51(1) Meas: W

(1) Purpose of filter

(2) Identify proper placement of a capacitive filter.

(3) Explain capacitive filter action in terms of

(a) charge and discharge paths.

(b) time constants.

(c) average output voltage.

(d) ripple amplitude.

(e) effect on average output voltage when the load or filter capacitance is varied.

(4) Identify proper placement of an inductive filter.

(5) Describe inductor filter action in terms of current regulation.

(6) Identify and explain the operation of the following filter configurations.

(a) capacitive input L.

(b) inductive input L.

(c) LC pi.

(d) RC pi.

(7) Purpose and placement of a bleeder resistor in terms of

(a) personnel safety.

(b) regulation.

(8) Purpose and possible placement of surge resistors and capacitors.

COURSE CONTENT

f. Given a schematic diagram of a semiconductor voltage doubler and the peak AC voltage, determine the peak output voltage. CTS: 5j(2) Meas: W (.5)

(1) Identify the schematic diagram.

(2) Explain operation in terms of

(a) current paths.

(b) ripple frequency.

(c) peak output voltage.

(3) Explain the method of changing the output polarity.

g. Given a schematic diagram and a list of statements, select the one which describes an operation taking place in a semiconductor voltage doubler. CTS: 5j(2) Meas: W (.5)

(1) Identify current paths during each alternation.

(2) Differentiate between charging and discharging resistance.

(3) Explain the summing effect of the voltages developed across the capacitors.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-34, Solid State Power Supply Rectifiers and Filters
KEP-ST-V, Solid State Power Supplies and Amplifiers
KEP-110

Audio Visual Aids
TVK 30-301A, Filters and Power Supplies
TVK 30-307, Voltage Doubler
TVK 30-236, Bridge Rectifiers

Training Equipment
LC-RC Filtering Characteristics Trainer 4865 (1)
Oscilloscope (1)
Multimeter (1)

Training Methods
Discussion (9 hrs) and/or Programmed Self Instruction
CTT Assignments (3 hrs)

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Multiple Instructor Requirements
Safety, Equipment, Supervision (2)

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

Instructional Guidance

Make specific objective assignments to be completed during CTT time in KEP-GP-34. Have students identify active components and direction of current flow through each type of rectifier a number of times. Discuss the rectifier output polarities, waveshapes(without filtering)and mathematical computations. An optional laboratory exercise can be performed to aid in reinforcing the theories discussed.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER V	BLOCK TITLE Solid State Power Supplies and Amplifiers

1 COURSE CONTENT	2 DURATION (Hours)
2. Solid State Power Supply Regulators (Module 35)	7 (5/2)

a. Given a schematic diagram of a zener diode shunt regulator and a list of statements, select the statement which describes the current path; the purpose of the series resistor. CTS: 5i(5) Meas: W

(1) Purpose and construction of a zener diode.

(2) Recognize the voltage regulating region on a zener diode characteristic curve.

(3) Purpose of the series resistor.

(4) Identify the

(a) schematic symbol.

(b) schematic diagram of a zener diode shunt regulator.

(5) Explain operation in terms of

(a) current paths.

(b) effects on output voltage for changes in AC input or load.

b. Given a schematic diagram of a series electronic voltage regulator and a list of statements, select the statements which give the effect on output voltage when the adjustment control is varied. CTS: 5i(5) Meas: W

(1) Identify the schematic diagram of series electronic voltage regulator.

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ATC FORM APR 75 133 ATC Keesler 6-1039 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

COURSE CONTENT

(2) Purpose of the zener diode in a series electronic voltage regulator.

(3) Describe the effect on biasing and voltage drops when the voltage adjust control is varied.

(4) With an input voltage change, explain the effect on resistance of the series transistor.

(5) Explain the effect on biasing of Q1 and Q2 as load is changed.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-35, Solid State Power Supply Regulators
KEP-ST-V
KEP-110

Audio Visual Aids
TVK 30-361, Voltage Regulators (Solid State)

Training Equipment
Electronic Voltage Regulator Trainer 5797 (1)
Multimeter (1)

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Multiple Instructor Requirements
Safety, Equipment, Supervision (2)

Instructional Guidance
Insure CTT time assignments are given in KEP-GP-35 and block V Student Text. Establish a need for voltage regulators and classify the types to be studied. An optional laboratory exercise, if performed, will require the students to use a variac, and this type of device will have to be briefly discussed.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles

BLOCK NUMBER V	BLOCK TITLE Solid State Power Supplies and Amplifiers

1 COURSE CONTENT	2 DURATION (Hours)
3. Troubleshooting Solid State Power Supplies (Module 36)	12 (9/3)
a. Given a multimeter, oscilloscope, schematic diagram, and a trainer having an inoperative solid state half-wave filtered power supply, determine the faulty component two out of three times. CTS: 2b, 2c, 5i(5) Meas: PC	(6)
(1) Review the power supply trainer, oscilloscope and troubleshooting procedures.	
(2) Describe the effects on the regulating circuit when the filtering network is inoperative.	
(3) Explain the effects on biasing of Q1 and Q2 for the following:	
(a) Q2 collector open.	
(b) Q2 biasing network open.	
(c) Zener diode bypassed.	
b. Given a multimeter, oscilloscope, schematic diagram, and a trainer having an inoperative solid state full-wave regulated and filtered power supply, determine the faulty component two out of three times. CTS: 1a, 2b, 2c, 5i(5) Meas: PC	(3)
(1) Review the power supply trainer, oscilloscope, and troubleshooting procedures.	
4. Measurement and Critique (Part 1 of 2 parts)	1
a. Measurement test	
b. Test critique	

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SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-36, Troubleshooting Solid State Power Supplies
KEP-ST-V
KEP-110
KEP-HO-18

Audio Visual Aids
TVK 30-352A, Power Supplies & Filters (T/S)
TVK 30-352B, Voltage Doublers (T/S)

Training Equipment
Power Supply Troubleshooting Trainer 5927 (1)
Oscilloscope (1)
Multimeter (1)
Meter Panel 4567 (1)

Training Methods
Performance (9 hrs)
CTT Assignments (3 hrs)

Multiple Instructor Requirements
Safety, Equipment, Supervision (2)

Instructional Guidance
Insure CTT time assignments are given in KEP-ST-V. Introduce the laboratory exercise and stress the value of practical application of theoretical knowledge. List the procedures which require caution to insure the safety of personnel and equipment. Have the class perform a dry run of the performance exercise before assigning them to the trainers. Inform students that Part 1 of the measurement test covers modules 34 through 36.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER V	BLOCK TITLE Solid State Power Supplies and Amplifiers

1 COURSE CONTENT	2 DURATION (Hours)
5. Troubleshooting Solid State Power Amplifiers (Module 37)	12 (9/3)
a. Given a list of statements, select the one which describes the effect of changing forward bias on push-pull amplifier class of operation; crossover distortion; efficiency. CTS: 5c Meas: W	(2.5)
(1) General Characteristics	
(a) Explain characteristics of power amplifiers in terms of power dissipation; of temperature stability; matching signal source impedance to load impedance; and need for heat sinks.	
(b) Given a transistor characteristic curve, identify the maximum power dissipation curve.	
(2) Push Pull (double ended)	
(c) Identify the schematic diagram of a class B transformer-coupled push-pull amplifier.	
(d) Describe the signal input requirements to a push-pull amplifier.	
(e) Purpose of the output transformer.	
(f) Explain the effects of forward bias changes on class of operation and efficiency.	
(g) Cause of cross-over distortion.	
(h) Identify a waveform that has cross-over distortion.	
(i) Explain how class AB operation reduces cross-over distortion.	

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COURSE CONTENT

(j) Explain how a balanced circuit provides even-harmonic cancellation.

b. Given the schematic diagram of a single stage paraphase amplifier, determine DC current path; output signal; voltage gain. CTS: 5c Meas: W (.5)

(1) Identify the schematic diagram

(2) Explain operation in terms of

(a) bandwidth

(b) voltage gain

(c) signal paths

(d) DC current path

(3) State the purpose of discharge diodes in RC-coupled, Class B, push-pull amplifiers.

c. Given the schematic diagram for a complementary-symmetry circuit using a common collector configuration, determine DC current paths; input signal requirements; output signals; source polarities. CTS: 5c Meas: W (1)

(1) Identify the schematic diagram of complementary-symmetry amplifier to include

(a) DC path

(b) input signal requirement

(c) output signals

(d) number and type of transistors

(e) voltage source polarities

(f) power gain

d. Given a schematic diagram for compound-connected power amplifier using a common base configuration, determine the DC current paths; the current gain. CTS: 5c Meas: W (1)

(1) Identify the schematic diagram of a compound-connected power amplifier using common base configuration.

(2) Explain operation in terms of

(a) direct-current paths.

(b) current gain

e. Given a trainer having an inoperative transistor push-pull power amplifier, schematic diagram, multimeter, and oscilloscope, determine the faulty component two out of three times. CTS: 1a,5c Meas: PC (4)

(1) Review troubleshooting procedure.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-37, Troubleshooting Solid State Power Amplifiers
KEP-ST-V
KEP-110
KEP-HO-37

Audio Visual Aids
TVK 30-359, Transistorized Push-Pull Amplifier
TVK 30-436, Complementary Symmetry

Training Equipment
Transistor Push-pull Amplifier Trainer 5969 (1)
Transistor Power Supply Trainer 4649 (1)
Oscilloscope (1)
Multimeter (1)
Signal Generator 4864 (1)

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
Performance (4 hrs)
CTT Assignments (3 hrs)

Multiple Instructor Requirements
Safety, Equipment, Supervision (2)

Instructional Guidance
Give students specific objectives to cover during CTT time in KEP-GP-37. Discuss amplifier class of operation as it is related to efficiency and fidelity. After explaining the various amplifiers from the standpoint of current paths, gain, efficiency and input/output polarities, have the students practice tracing current and identifying input/output phase relationships. Instruct the class to leaf through the laboratory exercise and generally familiarize themselves with the objectives, procedures and notes of safety.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER V	BLOCK TITLE Solid State Power Supplies and Amplifiers

1 COURSE CONTENT	2 DURATION (Hours)
6. Troubleshooting Solid State Narrow Band Amplifiers (Module 38)	8 (6/2)
a. Given a list of statements, select the one which describes the effects of load changes on Q and bandwidth of a narrow band amplifier. CTS: 5c Meas: W	(1)
(1) Narrowband amplifiers (RF)	
(a) Explain the result of using an LC tank in the output of an amplifier in terms of selectivity and sensitivity.	
(b) List the characteristics of a radio frequency transformer.	
(2) Given a frequency response curve,	
(a) identify the half power points.	
(b) determine the bandpass, bandwidth and center frequency.	
(3) Describe the effect of load changes on circuit	
(a) Q.	
(b) bandwidth.	
b. Given a list of statements, select the one which describes the effects of regenerative feedback on narrow band amplifier stability; distortion; gain. CTS: 5c Meas: W	(.5)
(1) Describe regenerative and degenerative feedback in terms of aiding or opposing the input signal.	

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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(2) Describe the effect of excessive feedback in an RF amplifier in terms of

(a) stability.

(b) distortion.

(c) gain.

(3) Describe the effects of degenerative feedback on an amplifier in terms of

(a) stability.

(b) distortion.

(c) gain.

c. Given frequency response curves for transformer coupling, select the one which identifies under coupling; over coupling; critical coupling. CTS: 5c Meas: W (.5)

(1) Given a two-stage amplifier, explain how impedance matching is accomplished when using

(a) transformer coupling.

(b) autotransformer coupling.

(c) pi network coupling.

(2) Given various transformer coupling response curves, identify the one that represents

(a) under coupling.

(b) over coupling.

(c) critical coupling.

d. Given schematic diagrams of narrow band amplifiers, identify the neutralization or unilateralization components. (1)
CTS: 5c Meas: W

(1) Explain need for neutralization circuits

(2) Given a schematic diagram of a neutralized RF amplifier, select the neutralization components.

(3) Explain need for unilateralization circuits

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(4) Given a schematic diagram of a unilateralized RF amplifier, select the unilateralization components.

e. Given a transistor radio frequency amplifier trainer, multimeter and oscilloscope, plot the frequency response curve and determine the bandpass and bandwidth at the half power points within ± 10 percent accuracy. CTS: 4g(1), 4g(2), 4g(3) Meas: PC (1)

(1) Review bandpass and bandwidth.

(2) Show relationships of bandpass and bandwidth to half-power points and Q.

f. Given a trainer having an inoperative transistor narrow band amplifier, schematic diagram, multimeter, and oscilloscope, determine the faulty component two out of three times. CTS: 5c Meas: PC (2)

(1) Review troubleshooting procedures.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-38, Troubleshooting Solid State Narrow Band Amplifiers
KEP-ST-V
KEP-110

Training Equipment
Solid State Radio Frequency Amplifier Trainer 5971 (1)
Solid State Power Supply Trainer 4649 (1)
Oscilloscope (1)
Mulitmeter (1)

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
Performance (3 hrs)
CTT Assignments (2 hrs)

Multiple Instructor Requirements
Safety, Equipment, Supervision (2)

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-38. Analyze each of the knowledge objectives contained in this module. Stress the strong relationship between these objectives and the laboratory exercises which follow. If the laboratory schedule permits, discuss each laboratory exercise separately before assigning students to the trainers. Have the class briefly scan the procedures and explain the desired outcomes, inconsistencies and troubleshooting techniques.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER V	BLOCK TITLE Solid State Power Supplies and Amplifiers

1 COURSE CONTENT	2 DURATION (Hours)
7. Solid State Wideband Amplifiers (Module 39)	7 (5/2)

a. Given a pictorial diagram of square wave and a list of statements, select the ones that identify the parts of the wave which contain high frequencies; contain low frequencies. CTS: 5d Meas: W

(1) Describe a square wave in terms of frequency content.

(a) Fundamental frequency

(b) Odd harmonics

(2) Identify the portions of a square wave containing high and low frequencies.

b. Given a list of statements, select the one which describes the purpose of stagger-tuning amplifier stages. CTS: 5d Meas: W

(1) Explain how stagger tuning broadens the bandwidth.

c. Given the schematic diagram for the video amplifier and a list of statements, select the statement which describes operation of the low frequency compensation components; the high frequency compensation components. CTS: 5d Meas: W

(1) Using a schematic diagram of a wideband amplifier, identify the

(a) components that attenuate the low frequencies.

(b) components that attenuate the high frequencies.

(2) Explain the operation of low frequency compensation in terms of collector load and gain.

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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ATC FORM APR 75 133 ATC Keesler 6-1020 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

(3) Describe high frequency compensation.

(4) Describe the frequency response of a wideband video amplifier.

d. Given a trainer having a solid state wideband amplifier, a square wave input, schematic diagram, and oscilloscope, draw the output waveshape indicating areas of low and high frequency distortion. CTS: 5d Meas: PC

(1) Explain the effects of low frequency loss if the low frequency compensating network is shorted.

(2) Describe the effects of an open low frequency compensating capacitor.

(3) Identify over-compensation for high frequencies and the resulting waveform.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-39, Solid State Wideband Amplifiers
KEP-ST-V
KEP-110

Audio Visual Aids
TVK 30-326, Square Wave Characteristics.
TVK 30-329, Video Amplifier

Training Equipment
Video Amplifier Trainer 5648 (1)
Oscilloscope (1)

Training Methods
Discussion (3.5 hrs) } and/or Programmed Self Instruction
Performance (1.5 hrs) }
CTT Assignments (2 hrs)

Multiple Instructor Requirements
Safety, Equipment, Supervision (2)

Instructional Guidance
Make specific objective assignments to be completed during CTT time in KEP-GP-39. After covering the knowledge objectives, introduce the laboratory exercise. Stress safety and discuss the procedures required to complete the project. Discuss the value of the laboratory exercise as a means of reinforcing objective c.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER V	BLOCK TITLE Solid State Power Supplies and Amplifiers

1 COURSE CONTENT	2 DURATION (Hours)
8. Saturable Reactors and Magnetic Amplifiers (Module 40)	5 (4/1)

a. Given the drawing of a hysteresis curve for a saturable reactor, identify the magnetizing force; the coercive force; the residual magnetism; the flux density; the point of saturation. CTS: 4h(1), 11f Meas: W

- (1) Relate the following terms to a magnetic circuit:
  - (a) Ampere turns
  - (b) Magnetomotive force
  - (c) Reluctance
  - (d) Magnetic flux
- (2) Relate the following terms to an electromagnet:
  - (a) Flux density
  - (b) Magnetizing force
  - (c) Permeability
  - (d) Coercive force
- (3) Draw and label a magnetization curve and explain
  - (a) residual magnetism.
  - (b) saturation.
  - (c) retentivity.
  - (d) hysteresis.

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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ATC FORM APR 75 133 ATC Keesler 6-1026 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(e) flux density.

(4) Identify the hysteresis loop of each of the following:

(a) Air-core coil

(b) Iron-core coil

(c) Saturable reactor

(5) State the purpose of a saturable reactor.

(6) Identify the schematic symbols of saturable reactors.

b. Given the schematic drawing of a single winding saturable reactor, AC line voltage, and saturating point, identify the output waveforms across the reactor winding; the load resistor. CTS: 4h(1) Meas: W

(1) Identify the schematic drawing of a single winding saturable reactor.

(2) Explain operation in terms of

(a) type of core.

(b) reactor winding.

(c) load.

(d) core saturation points.

(e) input and output waveforms.

c. Given a list of statements and the schematic diagram of a two-winding saturable reactor circuit, select the statement(s) that describe(s) control winding; load winding; load resistor; control adjustment; AC line voltage; control voltage; output waveforms. CTS: 4h(1) Meas: W

(1) Identify the schematic diagram and the

(a) load winding.

(b) control winding.

(c) load.

(d) saturation control.

(2) Explain operation in terms of

(a) control winding.

(b) load winding.

(c) load resistor.

(d) control adjustment.

(e) AC line voltage.

(f) control voltage.

(g) saturated interval.

(h) unsaturated interval.

(i) output waveforms.

d. Using a schematic diagram and a given set of conditions, develop output waveforms for an electrically connected magnetic amplifier.
CTS: 4h(2) Meas: W

(1) Identify the schematic diagram of a

(a) half-wave magnetic amplifier.

(b) full-wave magnetic amplifier.

(2) List practical applications of magnetic amplifier such as

(a) motor speed control.

(b) motor rotation directional control.

(c) light dimming (theaters).

(d) welding.

(3) Explain operation in terms of

(a) AC current paths.

(b) DC current paths.

(c) rectification.

(d) input waveform.

(e) output waveform.

COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-40, Saturable Reactors and Magnetic Amplifiers
KEP-ST-V
KEP-110

Audio Visual Aids
TVK 30-701, Saturable Reactors
TVK 30-702, Full-wave Magnetic Amplifier

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-40 and Student Text for block V. Establish a need for saturable reactors and the practical application of magnetic amplifiers. Discuss the importance of recalling previous studies in the area of magnetism. Refer the students to the appropriate area of KEP-ST-II.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
V	Solid State Power Supplies and Amplifiers

1 COURSE CONTENT	2 DURATION (Hours)

9. Synchro-Servo Systems (Module 41) — 7 (5/2)

a. Given a schematic diagram and a group of statements, select the statement that describes the operation of synchro system. CTS: 11c Meas: W

(1) Identify the need for synchro systems.

(2) Relate the schematic diagram of a synchro generator and motor to a synchro system.

(3) Distinguish between the synchro generator and motor.

(4) Determine, by the use of schematic, the electrical connections between synchro generator and motor.

(5) Explain synchro transformer action as related to rotor and stator.

(6) Relate electrical balance to unbalance between synchro generator and motor.

(7) Determine the effects of current flow in the generator and motor stator windings by repositioning the generator rotor.

(8) List the factors that affect the accuracy of synchro systems.

(9) Relate electrical zero to a synchro system.

b. Given the schematic diagram of a basic servo amplifier, identify the push-pull amplifier; the stabilization components; the feedback components. CTS: 11e Meas: W

(1) Basic circuits of a servo/amplifier.

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ATC FORM APR 75 133 ATC Keesler 6-1029 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 73, WHICH WILL BE USED.

(a) Error amplifier

(b) Power amplifier

(2) Given a schematic diagram, identify the

(a) differential amplifier.

(b) push-pull amplifier.

(c) stabilization components.

(d) feedback components.

(3) Trace an input error signal through the servo amplifier.

c. Given a block diagram and a group of statements, select the statement that describes the operation of a servo control system.
CTS: 11e   Meas: W

(1) Identify the block diagram of a basic servo control system which includes

(a) input shaft

(b) synchro generator

(c) control transformer

(d) servo amplifier

(e) servo motor

(f) output shaft

(2) Explain operation in terms of

(a) electrical and mechanical interconnections.

(b) differences between a synchro system and a servo system.

10. Measurement and Critique (Part 2 of 2 parts) 1

a. Measurement test

b. Test critique

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-41, Synchro-Servo Systems
KEP-ST-V
KEP-110

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

Audio Visual Aids
TVK 30-418, Introduction to Servo Amplifiers
TVK 30-753, Synchros
TVK 30-754, Servomechanisms

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Instructional Guidance
Give students specific objectives to cover during CTT time in KEP-GP-41. Discuss the symbols used to represent the various devices which comprise a basic servo system. Develop a basic block diagram of a servo loop to acquaint the students with the functional requirements and device interactions. Inform students that Part 2 of the measurement test covers modules 37 through 41.

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ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP-ST/Digest V

Technical Training

Electronic Principles (Modular Self-Paced)

Modules 34 - 41

DIGEST

15 June 1975

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

DO NOT USE ON THE JOB

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38

Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

Student Text 3AQR3X020-X
KEP-ST/Digest-V
15 June 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULES 34-41

DIGEST

These Digests provide a summary for each module in the course. The Digest is designed as a refresher for students with electronics experience and/or education who do not need to study any of the other resources in detail.

After reading a Digest, if you feel that you can accomplish the objectives of the Module, take the Module Self-Check in the back of the Guidance Package. If you decide not to take the self-check, select another resource and begin study.

CONTENTS

Module	Title	Page
34	Solid State Power Supply Rectifiers and Filters	1
35	Solid State Power Supply Regulators	5
36	Troubleshooting Solid State Power Supplies	7
37	Troubleshooting Solid State Power Amplifiers	8
38	Troubleshooting Solid State Narrow Band Amplifiers	12
39	Solid State Wideband Amplifiers	16
40	Saturable Reactors and Magnetic Amplifiers	19
41	Synchro-Servo Systems	21

MODULE 34

SOLID STATE POWER SUPPLY RECTIFIERS AND FILTERS

A half-wave rectifier consists of a power transformer, a single PN junction diode, and a load. The diode is connected in series, between the transformer and the load. Since the diode is in series with the load and conducts only in one direction, current through the load also flows in only one direction. The DC voltage across and the current through the load does vary but the variations are all above or below ground, depending on which way the diode is connected. The varying voltage is called PULSATING DC.

The variations occur because the diode follows the AC voltage in the secondary of the transformer. The diode conducts to the peak voltage of the transformer secondary. Ignoring the small resistance of the diode when it conducts, the peak voltage of the pulsating DC output is equal to the peak voltage by 1.414, or $E_{pk} = E_{eff} \times 1.414$. In a half-wave rectifier the diode conducts on every other alternation and the DC output varies from zero to the peak of the secondary. Although the output varies, the average can be determined by the formula $E_{avg} = E_{pk} \times .318$. The diode conducts on one alternation and is reverse-biased on the other. The reverse bias on the diode when it is not conducting is called the Peak Inverse Voltage and is equal to the peak voltage across the secondary. One DC pulse appears at the output each time the diode conducts. These pulsations are called RIPPLE. Since the diode conducts once during each cycle of the input AC, the ripple frequency of a half-wave rectifier is equal to the frequency of the input AC. The ripple frequency of the rectifier in figure 34-1 would be 60 PPS (Pulses Per Second).

The purpose of a full-wave rectifier is the same as a half-wave rectifier, or to change AC to DC. A full-wave rectifier consists of an input transformer with a center-tapped secondary, two diodes, and a load. The diodes are connected in such a way that one of them conducts on EVERY ALTERNATION of the AC input.

Because of the center-tapped secondary, the peak output voltage is equal to one-half the peak voltage across the entire secondary. The peak inverse voltage is equal to the peak voltage of the secondary. Average output voltage can be determined by multiplying peak output (E_{pk}) x .636. Since there are two diodes conducting on each alternation of the input, the ripple frequency of a full-wave rectifier is equal to TWICE the frequency of the input AC voltage.

A bridge rectifier is a full-wave rectifier, but it uses four diodes connected in a bridge arrangement. Notice that the transformer secondary is neither grounded nor center-tapped.

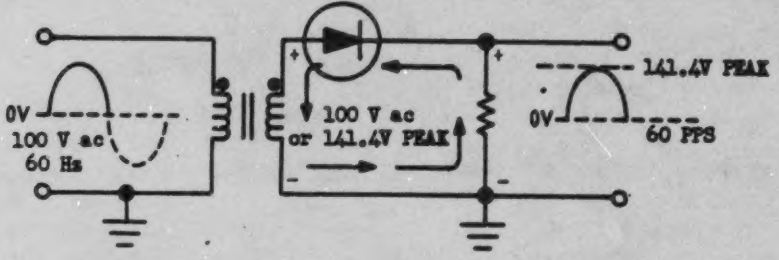


Figure 34-1. Half-Wave Rectifier

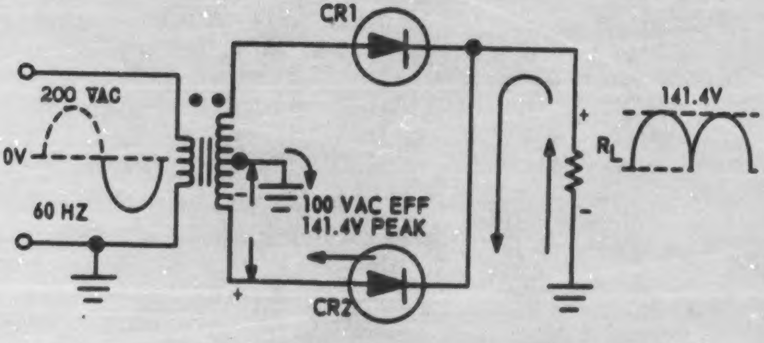
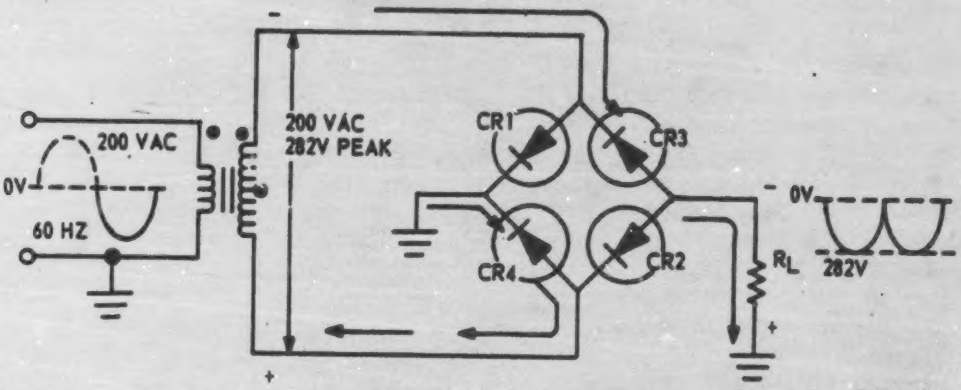


Figure 34-2. Full-Wave Rectifier

REP4-803



REP4-805

Figure 34-3. Bridge Rectifier

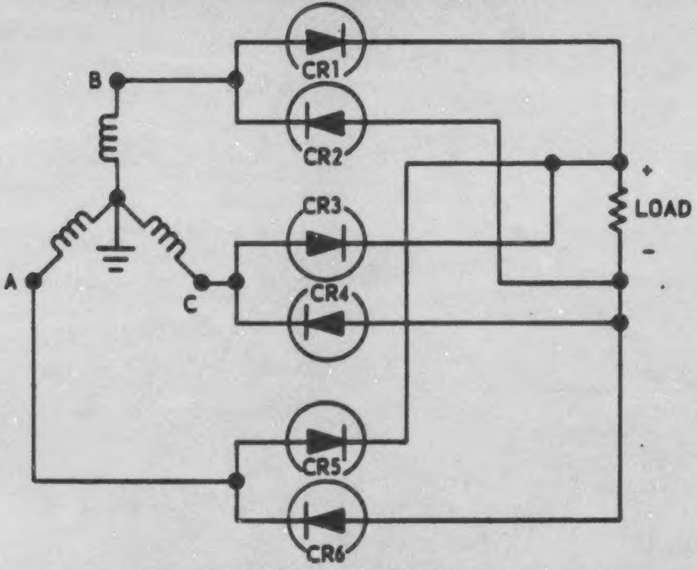
Because of this, two additional diodes are necessary to provide a complete path for current. The peak output voltage of a bridge rectifier is equal to the peak secondary voltage. The peak inverse voltage (piv) is also equal to the peak secondary voltage. Average output can be found by $E_{avg} = E_{pk} \times .636$. Ripple frequency of a bridge rectifier is equal to twice the frequency of the input AC.

Figure 34-4 shows a 3 phase full-wave rectifier. This rectifier provides full-wave rectification of three-phase AC voltage. Various combinations of the diodes form full-wave bridge rectifiers for each phase of the input. Notice that the three phases of the input overlap. This overlapping and the diode connections cause the ripple content of this rectifier to be very small. Consequently, very little filtering is required. Three-phase rectification means that the ripple frequency of this circuit is SIX times the frequency of the input AC voltage.

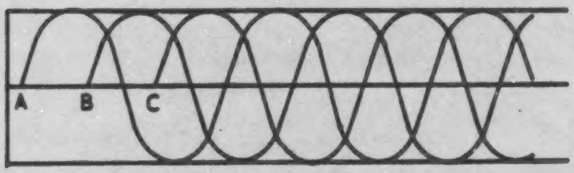
A voltage doubler is a circuit which converts AC to DC, provides filtering, and produces an output voltage which is approximately twice the peak voltage of the secondary. See figure 34-5.

Capacitor C1 and C2 each charge to the peak secondary voltage on alternate cycles of the applied voltage. The charged capacitors acts as series-aiding batteries and the voltage across the load is the sum of the charges on C1 and C2.

Most electronic equipment requires a smooth DC that approaches the ripple-free output of a battery. Filters are used to convert pulsating DC to smooth DC. A filter can be a capacitor at the output of a rectifier and in shunt with the load. Due to the


B
A
C
CR1
CR2
CR3
CR4
CR5
CR6
+
LOAD
-

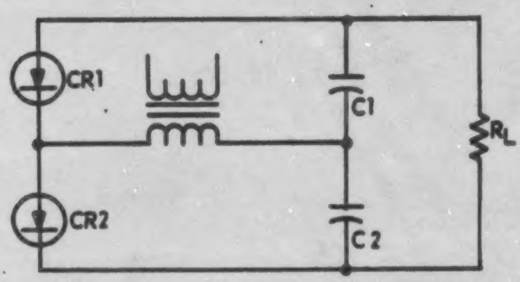
A. THREE-PHASE FULL-WAVE RECTIFIER



B. THREE-PHASE WAVESHAPES

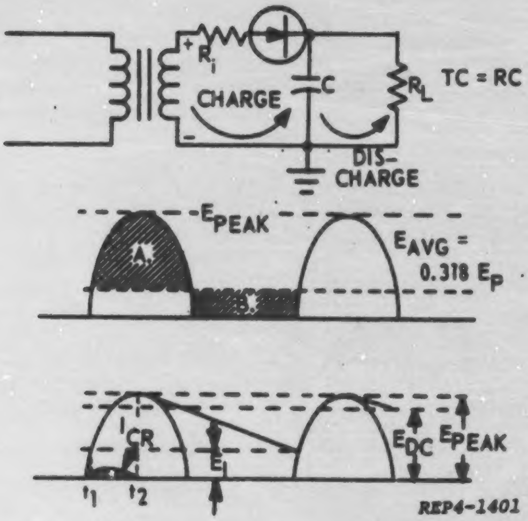
REP4-810

Figure 34-4


CR1
CR2
C1
C 2
R_L

REP4-1400

Figure 34-5. Voltage Doubler

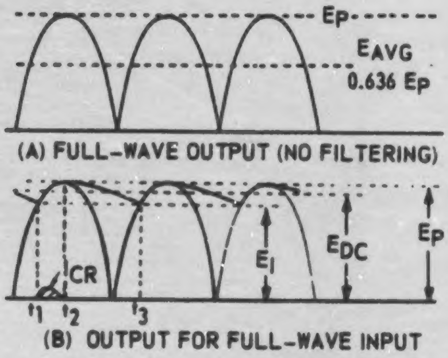


REP4-1401

Figure 34-6. Half-Wave Rectifier

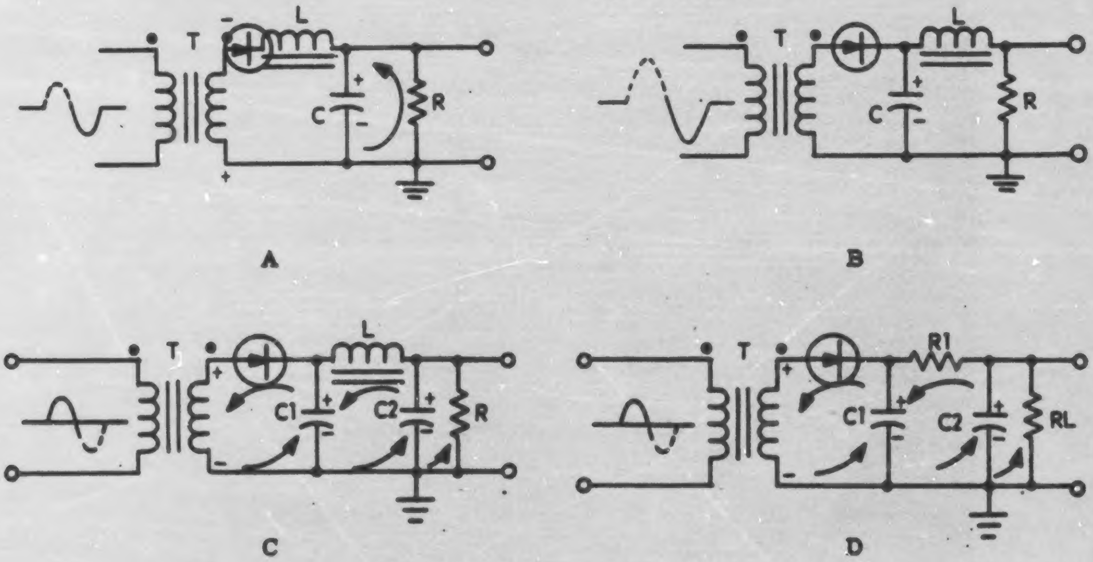
load and current requirements, a filter usually consists of a combination of capacitors and inductors or capacitors and a resistor.

Figure 34-6 shows a half-wave rectifier with a simple capacitive filter, along with diagrams of the filtered and unfiltered output. The capacitor charges quickly through the low internal impedance of the diode (short time constant) and discharges through relatively large impedance of the load (long time constant). The long time constant discharge path through the load prevents the capacitor from completely discharging during the time the diode is not conducting. This, in turn, prevents the output DC from ever reaching zero. The filtering action reduces the ripple content and increases the average DC output. Figure 34-7 shows the filtered and unfiltered output of a full-wave rectifier.



REP4-1235

Figure 34-7



A

B

C

D

Figure 34-8. Filter Combinations

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The addition of an inductor (choke) in series with the load helps to increase filtering action, provides better regulation, and allows a larger load (greater current). Figure 34-8 shows the various LC filter combinations to include the choke input L, capacitive input L, and LC Pi. Sometimes, the choke in the Pi type filter is replaced by a resistor and called an RC Pi.

MODULE 35

SOLID STATE POWER SUPPLY REGULATORS

Voltage regulators are designed to prevent the output voltage of a power supply from changing, even though the input AC or the load varies. In this section, we will discuss two types: the zener diode shunt regulator and the electronic voltage regulator (EVR).

Zener diodes are designed to work with reverse breakdown voltages applied and operate in the avalanche region of the characteristic curve. Because of the area in which these diodes work, they are sometimes called breakdown or avalanche diodes. Figure 35-1 shows the characteristic curve of a typical zener diode. Notice that the diode breaks down at point A with about 43 volts of reverse bias applied. At this point, 3 mA of reverse current flows. At point B the current has increased to 22 mA, but the voltage drop across the diode is only 45V. Between points A and B the current changes 19 mA but the voltage only changes 2 volts.

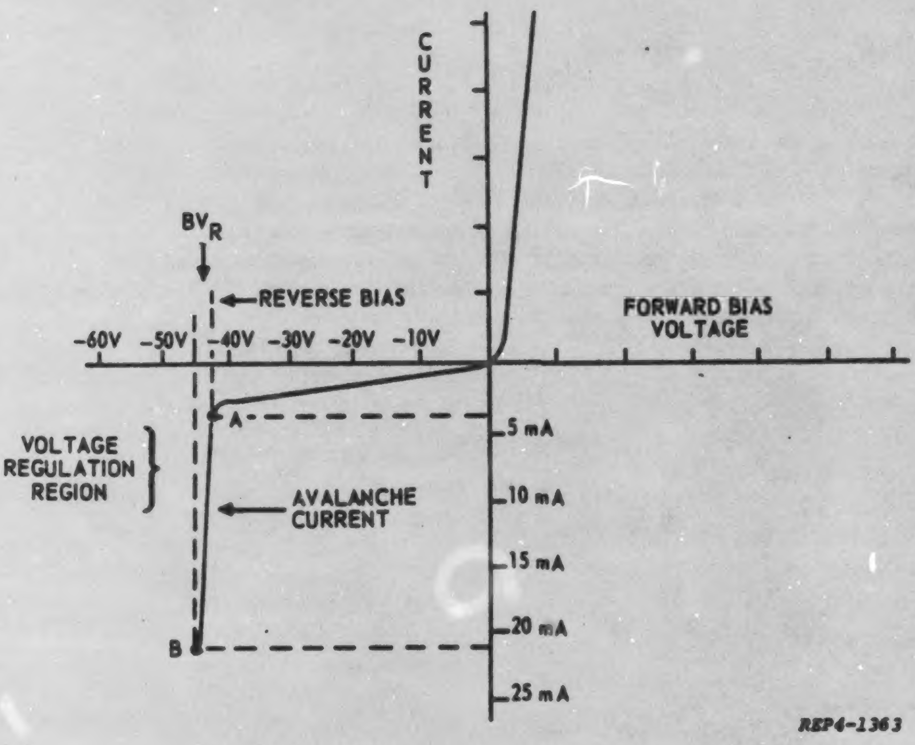
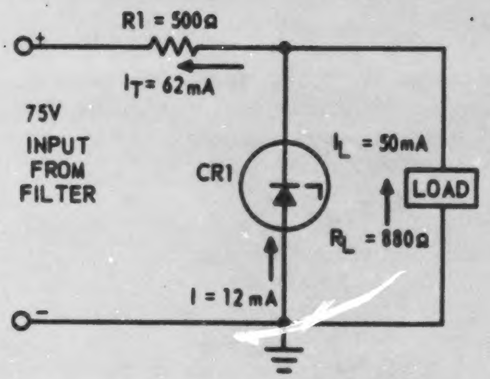


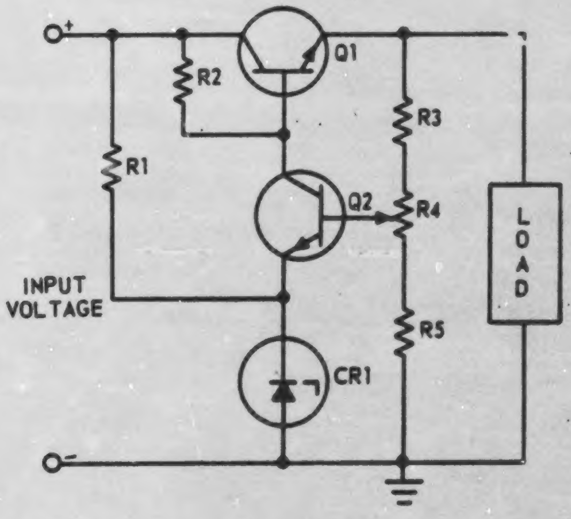
Figure 35-1. Zener Diode Characteristic Curve



REP4-1439

Figure 35-2. Zener Voltage Regulator Circuit

Figure 35-2 shows a regulator circuit using a zener diode. CR1 is in parallel with the load. R1 is a current limiting resistor in series with the load. Any change in input voltage or load causes a change in current through CR1; this in turn, changes the total current through R1 and a change in voltage drop across R1. If, for example, the input voltage decreases, current through CR1 decreases. This causes I_T through R1 to decrease, drop less voltage and hold the load voltage constant. There are two key points to remember. First, the current through CR1 can vary, but the voltage across it remains relatively constant. Second, since R1 is in series with the load, the voltage drops across it and the load must add up to the applied voltage. Any change in current through CR1 causes a change in voltage drop across R1, which always works to hold the voltage across the load constant.



REP4-1438

Figure 35-3. Electronic Voltage Regulator

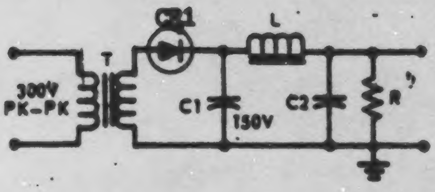
The series dropping resistor R1 in the circuit just discussed can be replaced by a transistor, which is much more sensitive to changes in current and voltage and has a faster reaction time. Such a circuit is shown in figure 35-3. Q1 is in series with the load and replaces R1 in the previous circuit. Q2 and the voltage divider network R3, R4, and R5 make up a sensing circuit which causes the resistance of Q1 to change. CR1 holds the emitter voltage of Q2 constant. R1 is the current limiting resistor for CR1. R2 is the collector load for Q2 and the forward bias resistor for Q1. R4 is the voltage adjust control, which sets up the level around which the circuit regulates.

Let's suppose the input voltage starts to increase. An increase in applied voltage is immediately felt across the voltage divider R3, R4, R5. The voltage at R4 and the base of Q2 goes positive. Since the emitter of Q2 is held constant, the positive going change on the base results in an immediate increase in forward bias. The increase in forward bias on Q2 causes the collector current to increase. The increase in collector current causes the drop across R2 to increase and the voltage at the base of Q1 to decrease. The decrease in voltage at the base of Q1 decreases forward bias and increases voltage drop which lowers the output. These changes are almost instantaneous. Any change in input or load causes the voltage across the divider network to change, which is sensed by Q2 and causes the resistance of SERIES REGULATOR (Q1) to change. R4 controls the voltage level about which the circuit regulates. If the arm of R4 is moved up, the voltage at the base of Q2 goes more positive, increasing forward bias and collector current. The increase in collector current causes an increased drop across R2, a decrease in forward bias of Q1, and increases the resistance of Q1. When the resistance of Q1 increases the output voltage decreases. The circuit now regulates around a lower voltage. Moving the arm of R4 down causes the output voltage to increase.

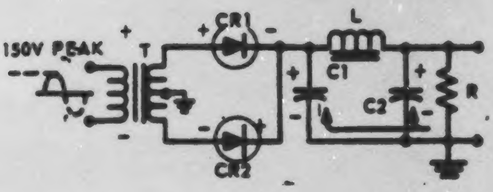
MODULE 36

TROUBLESHOOTING SOLID STATE POWER SUPPLIES

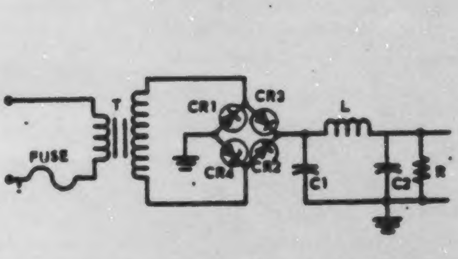
In troubleshooting the power supplies previously discussed, we will cover the effects on output voltage, ripple amplitude, and ripple frequency of shorted or open capacitors and diodes. Following are three power supply schematics (figure 36-1) with troubleshooting tables (Table 36-1) for each.



A. Filtered Half-Wave Rectifier



B. Filtered Full-Wave Rectifier



C. Filtered Bridge Rectifier

Figure 36-1

Table 36-1

SUMMARY OF TROUBLESHOOTING

A. HALF-WAVE

Trouble	Output Voltage	Ripple Amplitude	Ripple Frequency
CR Open	No output	None	None
CR Short	No output Blown fuse	None	None
C Open	Lower than normal No filtering	Greater than normal	No change
C Short	No output Blown fuse	None	None

B. FULL-WAVE

Trouble	Output Voltage	Ripple Amplitude	Ripple Frequency
Diode Open	Lower than normal Half-wave rectification	Greater than normal	Decrease by 1/2
Diode Short	No output Blown fuse	None	None
C Open	Lower than normal Filtering decrease	Greater than normal	No change
C Short	No output Blown fuse	None	None

C. BRIDGE

Trouble	Output Voltage	Ripple Amplitude	Ripple Frequency
Diode Open	Lower than normal Half-wave rectification	Greater than normal	Decrease by 1/2
Diode Short	No output Blown fuse	None	None
C Open	Lower than normal Filtering decrease	Greater than normal	No change
C Short	No output Blown fuse	None	None

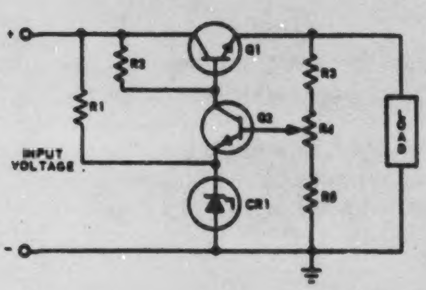


Figure 36-2. Schematic of an EVR

Figure 36-2 is the schematic of an EVR. Two things are important in troubleshooting this circuit; the amplitude of the output voltage and the ability of the circuit to regulate. Assume the output is higher than normal and there is no regulation. CR1 could be open. With CR1 open, Q 2 cannot conduct and the voltage on the base of Q1 will be very high. The resistance of Q1 would be low and the output higher than normal. There is no regulation because Q2 cannot sense voltage changes. R3 open causes the same symptoms. With R3 open, the voltage on the base of Q2 is near zero and the base of Q1 highly positive as before. Q1 shorted will also cause the output to be high and unregulated. A symptom of no output voltage could be caused by Q1 or R2 open. With Q1 open the series circuit is broken. If R2 opens, there is no forward bias for Q1.

MODULE 37

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

The last stage of a series of amplifiers is usually the power amplifier. Power amplifiers are designed to achieve maximum power gain. Transistors working at high power levels have certain limitations. One of these is the amount of power they can dissipate. The maximum power dissipation (PD_{MAX}) rating of a transistor is the maximum power it can dissipate without danger of being destroyed. Figure 37-1 shows a PD_{MAX} curve for a type 2N1067 transistor. Notice that at any point on the curve the product of V_C I_C is 5 watts. The transistor must not be operated to exceed 5 watts of collector dissipation. Another limitation of transistors working at high power levels is the heat generated internally. Transistors become unstable as junction temperature increases. Heat sinks, in the form of cooling fins, are used to move heat away from the junctions.

One commonly used power amplifier is the double-ended or PUSH-PULL amplifier. Figure 37-2 shows a push-pull power amplifier. The circuit is forward biased through R1 and the two halves of the center-tapped secondary of T1. As shown, the circuit

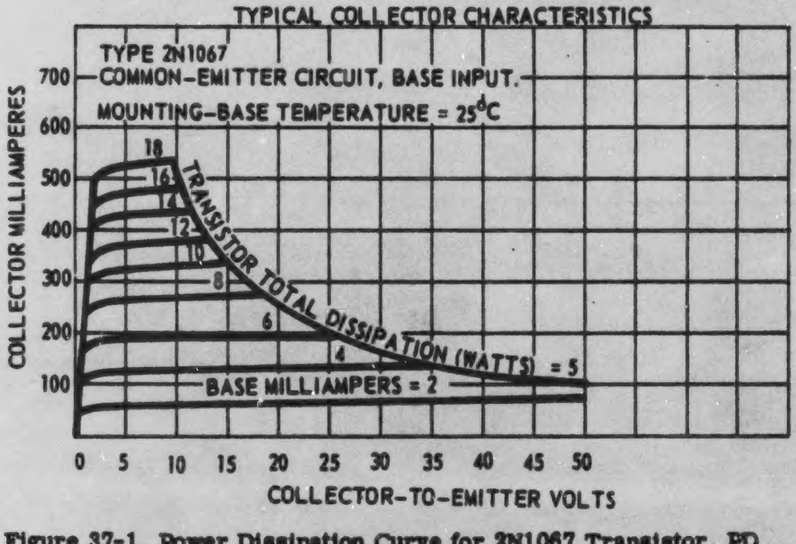


Figure 37-1. Power Dissipation Curve for 2N1067 Transistor, PD_{MAX}

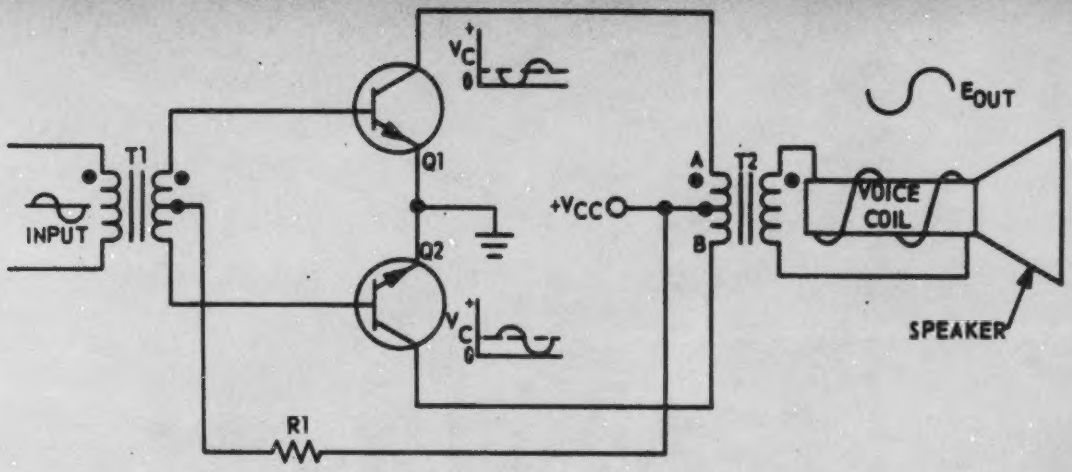


Figure 37-2. Class A, Push-Pull Power Amplifier

operates class A, but for better efficiency, it can be operated class B. If the center tap is grounded rather than returned to V_{CC} through R1, the circuit will operate class B. The secondary of T1 is center-tapped to provide two signals 180° out of phase but equal in amplitude to the bases of Q1 and Q2. The out of phase signals cause Q1 to increase in conduction on one alternation of the input and Q2 on the other. The primary of output transformer T2 is also center-tapped. The top half of the primary of T2 is the collector load for Q1. On the alternation when Q1 conduction increases, the changing current in the top half of the primary induces a current in the secondary and one alternation is reproduced. On the other alternation, Q2 current through the bottom half of the primary, reproduces the other alternation at the output. It can be said that T2 recombines the signals which were split at the secondary of T1. If Q1 and Q2 are balanced, all even harmonics are cancelled. Balancing can be done by putting a variable resistance in the circuit which is common to the emitters of Q1 and Q2. The power output of a push-pull amplifier can be MORE than twice that of a single-ended power amplifier. When a push-pull amplifier is operated at any class except A, it is subject to a type of distortion called CROSS-OVER distortion. Figure 37-3 shows an example of cross-over distortion in a push-pull amplifier. This type of distortion is due to the fact that the SIGNAL provides the forward bias for the transistors. When one signal decreases in amplitude, one of the transistors is operating in the low forward bias area of its curve and distortion occurs. A short time later, the other transistor starts to conduct and produces distortion. This distortion always occurs around the point where one transistor is going off and the other coming on. Therefore, it is called CROSS-OVER distortion. Cross-over distortion can be eliminated or reduced by applying a small DC forward bias or by operating class AB.

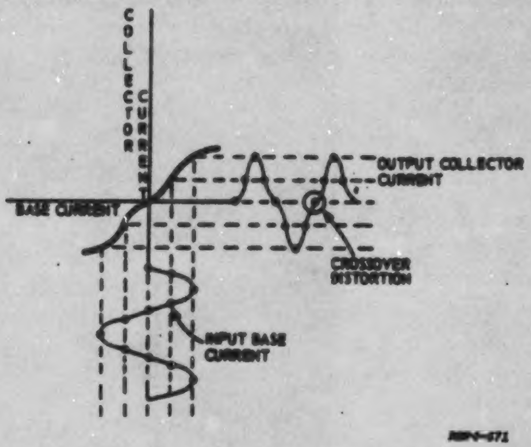
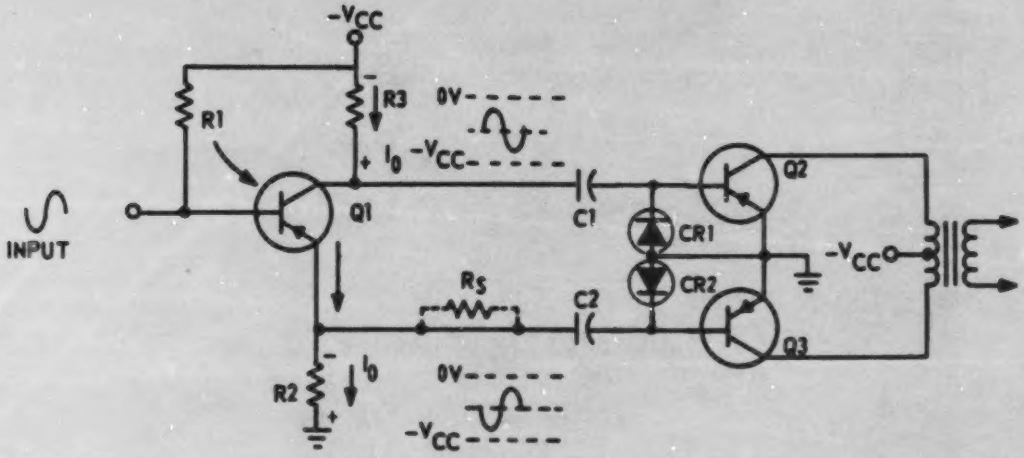


Figure 37-3. Class B Push-Pull Waveforms (Cross-Over Distortion)



REP4-676

Figure 37-4. One-Stage Phase Splitter

We mentioned earlier that the input transformer of a push-pull amplifier splits the input into two, equal amplitude, 180° out of phase signals. An electronics circuit which will accomplish this is the paraphase amplifier or phase SPLITTER.

Figure 37-4 shows a paraphase amplifier connected to a push-pull amplifier.

The signals at the emitter and collector of Q1 are 180° out of phase and will be equal in amplitude at the bases of Q2 and Q3. R_S increases the low emitter output impedance of Q1 to match the higher collector impedance. Q2 and Q3 are operated class B with forward bias provided by the signals coupled through C1 and C2. In order to prevent the signal from shifting the operating point of Q2 and Q3, discharge diodes are connected to the bases. They serve as discharge paths for C1 and C2 when the signals swing negative. The voltage gain of a paraphase amplifier is less than one. The low gain causes the bandpass to be greater. The frequency response of this circuit is much better than that of a center tapped transformer.

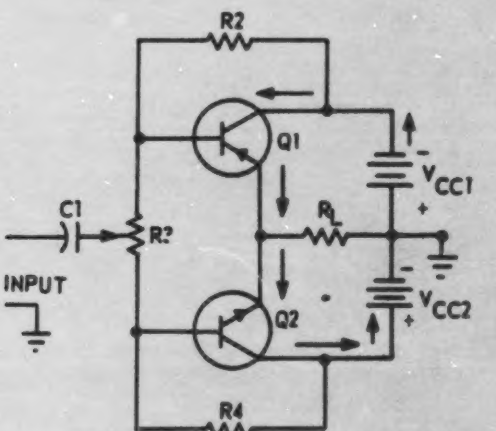


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Figure 37-5. Complementary-Symmetry Circuit

A circuit similar to the push-pull amplifier, but without the need of either an input transformer or phase-splitter is the complementary-symmetry amplifier shown in figure 37-5. The circuit does not need out of phase signals because Q1 is a PNP transistor and Q2 is an NPN. The signal is applied to both bases through balance resistor R3. When the signal goes positive, both bases go positive. This action causes Q2 conduction to increase and Q1 to decrease. When Q2 conducts, current flows from ground through R_L, Q2, to V_{CC2} and reproduces the positive alternation across R_L. Q1 conducts from V_{CC1}, Q1, through R_L to ground and reproduces the negative alternation across R_L. The load, R_L, might be the voice coil of a speaker in

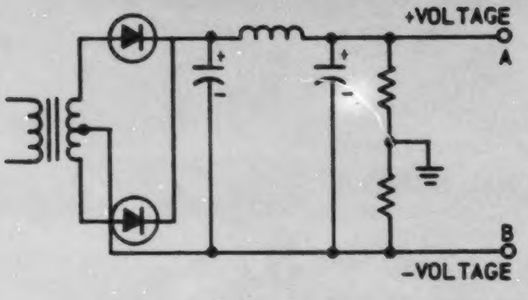

Figure 37-6. Power Supply for a Complementary-Symmetry Amplifier

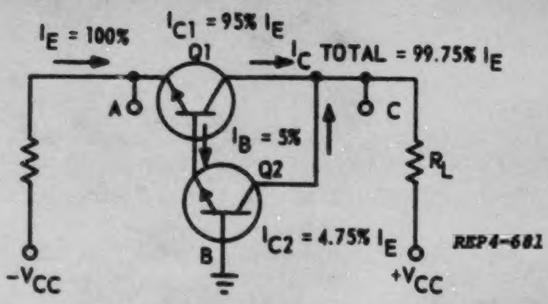

Figure 37-7. Compound-Connected Common Base

place of the resistor as shown. Notice that two batteries are used so as to apply the correct polarity of V_{CC} to the two transistors. When an electronic power supply is used, both positive and negative voltages can be obtained from the same power supply. A common method of doing this is shown in figure 37-6.

The current, voltage, and power gains of a common base amplifier are directly related to the forward current transfer ratio (alpha). This is the ratio of I_C to I_E and the greater this ratio, the greater the current gain. A circuit which is designed to increase alpha is the COMPOUND-CONNECTED amplifier shown in figure 37-7. Q1 and Q2 are both connected in common base configuration. Notice that the base current of Q1 is the emitter or input current of Q2. Notice also that the two collector currents add in R_L. Assume each transistor has an alpha of .95 and that the input current to Q1 is 10 mA. Since alpha is .95, I_C for Q1 is 9.5 mA. Base current for Q1 is therefore, .5 mA. Input or emitter current for Q2 is also .5 mA. Alpha of Q2 is also .95, so I_C for Q2 is .475 mA. I_T is $I_{CQ1} + I_{CQ2}$ or 9.975 mA. Alpha for the circuit is $\frac{9.975 \text{ mA}}{10 \text{ mA}}$ or .9975, which is a considerable increase over .95.

Figure 37-8 shows a push-pull amplifier. R3 is a balancing resistor and the transistors are forward biased by R1 and R2. C1 places the center tap of the transformer at AC ground. In troubleshooting this circuit, the things to look for are the output signal, its amplitude, cross-over distortion, and the proper DC voltages. For example, if the primary of T1 or secondary of T2 open, all DC voltage would be normal but there would be no output signal. If the secondary of T1 or primary of T2 open, one or both of the transistors would be off and the output missing or weak and distorted. If R1 and C1 shorts or R2 opens, the transistors would operate class B and cross-over distortion

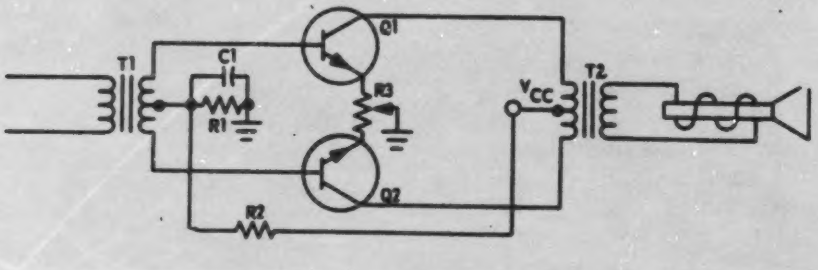

Figure 37-8. Push-Pull Amplifier

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would be present. Should R1 open, the forward bias would increase, V_C would be low on both transistors and the output would be larger than normal with possible distortion. C1 open would cause degeneration and the output would be smaller than normal but all DC voltages would be correct. Shorting R2 would place V_{CC} on the base leads. This would cause excessive forward bias, possibly a blown fuse and/or destruction of the transistors. If the wiper arm of R3 opened, both transistors would cut off. There would be no output signal and V_C on Q1 and Q2 would equal V_{CC}.

MODULE 38

TROUBLESHOOTING SOLID STATE NARROW BAND AMPLIFIERS

Amplifiers which operate in the RF band of frequencies are sometimes called NARROW BAND amplifiers. Such an amplifier is shown in figure 38-1. R1 and R2 provide forward bias for Q1. C2 and C5 are decouplers and isolate the RF signal from the power supply. R4 is the DC load. The received signal is developed across the input tank, C1 and T1 primary. The signal is coupled to the base of Q1 by T1. The output signal is developed across collector tank circuit C4 and primary T2. T2 couples the signal to the next stage. The input and output tank circuits are gang-tuned to the same frequency to improve selectivity.

A single stage is seldom sufficient to provide the required RF amplification. When two or more RF stages are connected in cascade, the resultant bandwidth is considerably more narrow than that of a single stage. Figure 38-2 shows two RF amplifiers in cascade, along with 3 tuned circuits required to develop and couple the signal. Figure 38-3 shows the response curves for the first tuned circuit, first stage, and the resultant response curve for the entire circuit. Curve 3 shows the response for the entire circuit and indicates that the bandwidth is considerably more narrow than for one stage alone. Notice that the frequencies

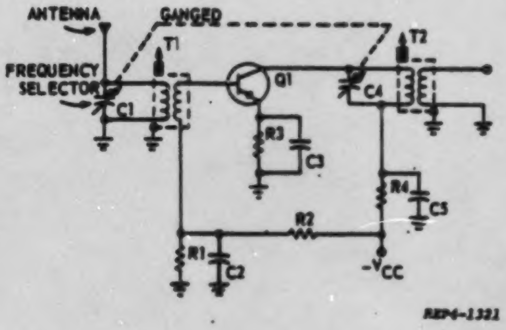

Figure 38-1. Transistor RF Amplifier

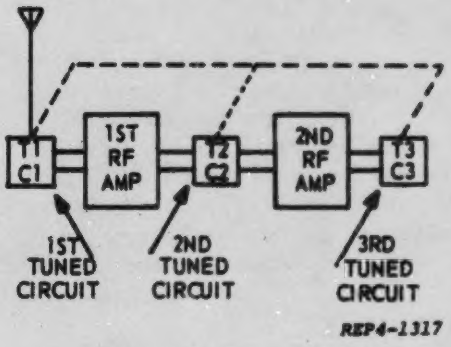

Figure 38-2. Block Diagram of Cascaded RF Amplifiers

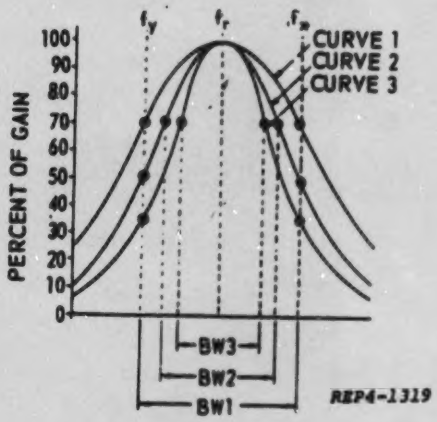

Figure 38-3. Response Curves for Cascade-Tuned Circuits

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at the half-power points on curve 1 (first tuned circuit) are down to 30% of the maximum on curve 3. It is necessary that the bandwidth for each stage be wider than that required for the overall receiver. Figure 38-3 also indicates that several RF stages increase the slope of the response curve and increases the selectivity.

Noise voltages falling within the bandpass will be amplified along with the signal, and those whose frequencies are outside the bandpass are not amplified. Noise at the limits of the bandpass can be minimized by decreasing the bandwidth, which increases signal-to-noise ratio.

Using figure 38-4, let's now troubleshoot the RF amplifier. As we cover various malfunctions, keep in mind the relationship of BW, selectivity, gain, and signal-to-noise ratio.

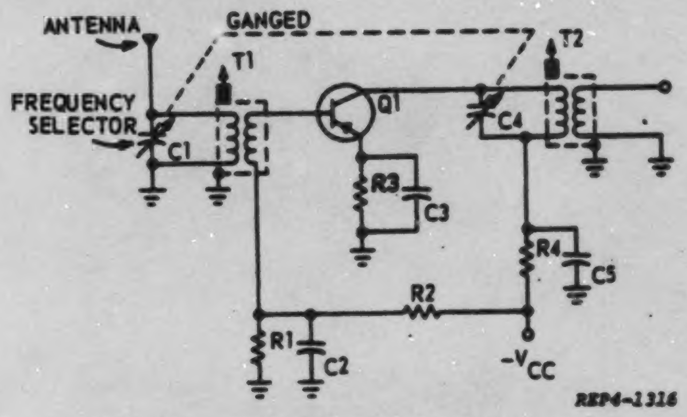

Figure 38-4. Transistor RF Amplifier

MALFUNCTIONS	SYMPTOMS
C1 open	Output amplitude decreased, bandwidth increased, signal-to-noise ratio decreased, DC voltages normal, resonant frequency of first tank circuit increased.
Primary T1 open	No output, all DC voltages normal.
C4 open	Output amplitude lower than normal, bandwidth increased, signal-to-noise ratio decreased, resonant frequency of output tank uncontrollable and higher than normal.
Primary T2 open	No output signal; V_{CQ1} is zero.
C1 or primary T1 shorted	No output signal; DC voltage normal.
C4 or primary T2 shorted	No output at secondary of T2, V_C slightly higher than normal.
Secondary T1 shorted	No output signal, forward bias slightly increased, V_C a little lower than normal.
Secondary T2 shorted	No output, all DC voltages normal.

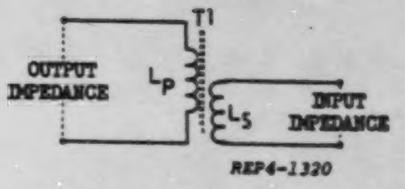
T1
OUTPUT IMPEDANCE
L_P
L_S
INPUT IMPEDANCE
REP4-1320

Figure 38-5. RF Transformer-Impedance Matching

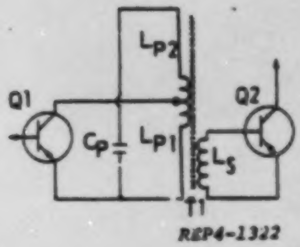
L_{P2}
Q1
Q2
C_P
L_{P1}
L_S
T1
REP4-1322

Figure 38-6. Partial Schematic of Interstage Transformer Coupling

Transformers used for interstage coupling of RF energy have different characteristics than those used at audio frequencies. Because of sensitivity and selectivity requirements, the tuned coupling circuits need to have a relatively high Q. Permeability tuning increases inductance and Q, and also reduces physical size and stray winding capacitance. One function of coupling transformers is to match the output impedance of one stage to the input impedance of the next. As shown in figure 38-5, this can be done by adjusting the turns ratio. When the turns ratio is correct, impedances are matched and maximum power transfer occurs. When the secondary is loaded, the Q of the primary decreases and may affect selectivity. This can be overcome by tapping the primary to maintain the correct turns ratio for impedance matching. The additional turns increase the inductance and restores the Q and selectivity. Figure 38-6 shows an example of this method of coupling. Tapped autotransformers may be used for interstage coupling. Figure 38-7A shows an autotransformer tapped for impedance matching only. Figure 38-7B shows a multi-tapped transformer used for impedance matching and Q restoration. Split capacitors may also be used for impedance matching in coupling networks. Figure 38-8 is an example of "Pi" network coupling using split capacitors for impedance matching. If C2 is larger than C1, its impedance will be less. Thus, the output impedance of Q1 can be matched to the input of Q2. Figure 38-8A shows a Pi network for impedance matching only. Figure 38-8B shows a Pi network used for both impedance matching and Q restoration.

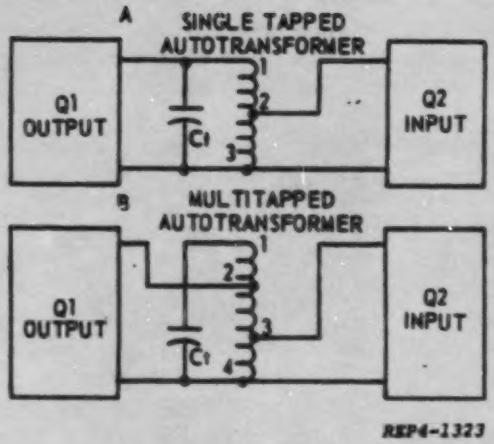
A
SINGLE TAPPED AUTOTRANSFORMER
Q1 OUTPUT
C_1
1
2
3
Q2 INPUT
B
MULTITAPPED AUTOTRANSFORMER
Q1 OUTPUT
C_1
1
2
3
4
Q2 INPUT
REP4-1323

Figure 38-7. Autotransformer Coupling

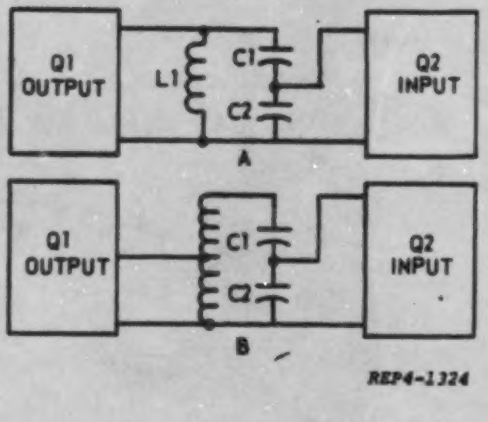
Q1 OUTPUT
L1
C1
C2
Q2 INPUT
A
Q1 OUTPUT
C1
C2
Q2 INPUT
B
REP4-1324

Figure 38-8. Capacitance Coupling Using Split Capacitors

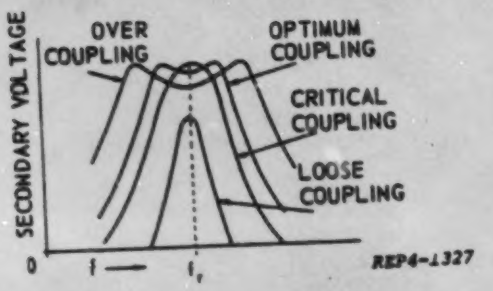

Figure 38-9. Double-Tuned Transformer Response Curves

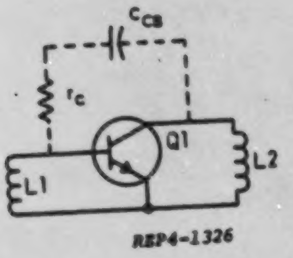

Figure 38-10. Feedback through an Amplifier

Some circuit applications require both a wide bandwidth and a high Q. Single-tuned coupling transformers cannot achieve both. When necessary, double-tuned transformers (both primary and secondary are permeability tuned) may be used. Double-tuned transformer bandwidth characteristics depend partially on the degree of coupling between windings. Figure 38-9 shows how the bandwidth changes with different amounts of coupling.

Feedback is defined as the transferral of energy from a high level point in a system back to a low level point. For example, if the signal at the collector of a common emitter amplifier (high-level point) is returned to the base (low-level point), it is called feedback. In some cases, feedback is through an amplifier itself, and in others through the external circuitry. There are two types of feedback. Regenerative feedback, which increases gain, is generally not used in RF amplifiers because it can cause instability and distortion. In addition, it can cause the amplifier to break into oscillation.

Degenerative feedback increases stability and fidelity, decreases distortion, and gain which results in an increased bandwidth. Undesirable regenerative feedback may occur through the internal resistance and capacitance of an amplifier. Figure 38-10 shows how this can take place. Q1 is the amplifier, L1 and L2 represent the resonant coupling circuits at the input and output, and r_c and C_{CB} indicate internal resistance and capacitance. Q1 shifts the phase of the signal by 180°. C_{CB} and r_c can shift the signal phase by another 180° and feed it back to the base as regenerative feedback. This may cause instability and distortion. A process called "unilateralization" can be used to cancel the effects of regenerative feedback through internal capacitance and resistance. Figure 38-11 shows how this is done. Q1 shifts the signal phase by 180°. C_{CB} and r_c shift this signal by another 180° and feed it back to the base as regenerative feedback. The output transformer also shifts the signal phase by 180°. The signal at the secondary of the output transformer is, therefore, in phase with the base signal. If R_u and C_u are the same size as r_c and C_{CB}, they will shift the phase of the output signal by another 180°, feed it back to the base as degenerative feedback and cancel the internal

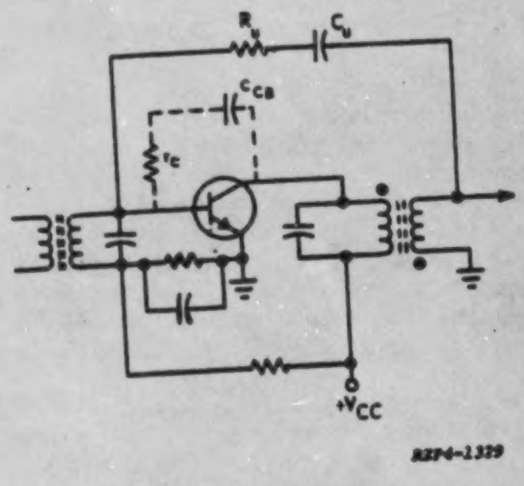

Figure 38-11. Unilateralized Tuned Amplifier

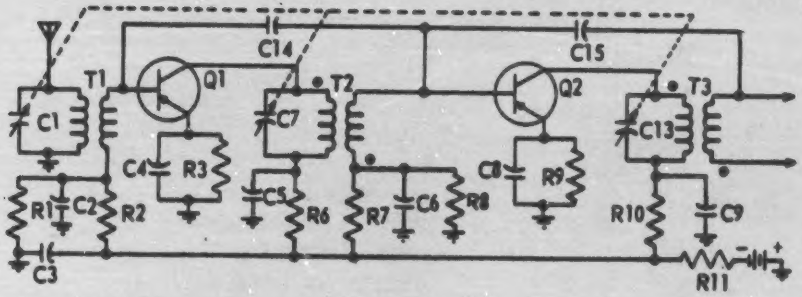

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Figure 38-12. Two-Stage RF Amplifier

feedback. When regenerative feedback takes place through distributed capacitance, "neutralizing" capacitors may be used to cancel it. The circuit in figure 38-12 is a two-stage RF amplifier. Capacitors C14 and C15 are neutralizing capacitors and cancel any regenerative feedback which occurs because of distributed capacitance.

MODULE 39

SOLID STATE WIDEBAND AMPLIFIERS

A very important factor in some applications of amplifiers is the ability to amplify nonsinusoidal signals. These include sawtooth, trapezoidal, and square waves. The waves consist of some fundamental frequency plus a large number of harmonics. To faithfully reproduce the signal, an amplifier must amplify the fundamental and all harmonics equally. This type of amplifier is called a wideband or video amplifier. Television and video signals are usually square or rectangular waves. A square wave consists of a fundamental frequency plus an infinite number of odd harmonics. This means that an amplifier must be able to amplify a wide range of frequencies in order to reproduce a square wave. Figure 39-1 represents a square wave and shows its different dimensions.

The vertical leading and trailing edges of the wave contain the high frequencies. The flat tops and bottoms contain low frequencies.

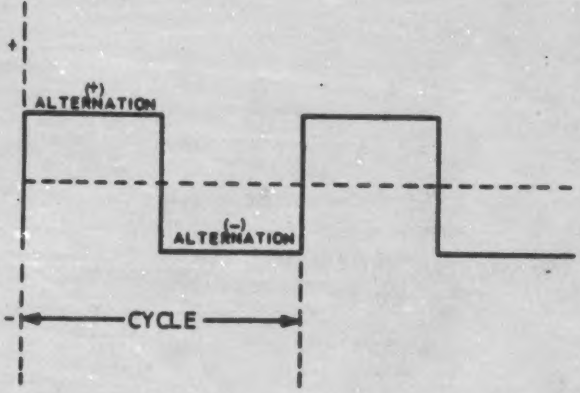

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Figure 39-1. Square Wave

The frequency range of a video amplifier (typical wideband amplifier) must be from about 10 hertz to around 4 megahertz. Two frequency response limitations must be overcome before a standard amplifier can be used for wideband amplification. Figure 39-2

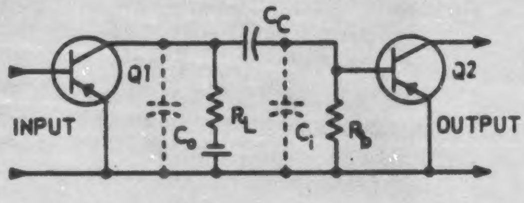

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Figure 39-2. RC Coupled Amplifier Showing Capacitive Effect at High Frequencies

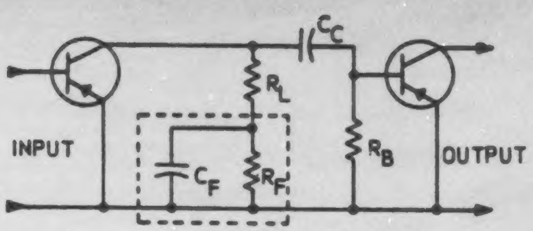


Figure 39-3. Wideband Amplifier, Low Frequency Compensation

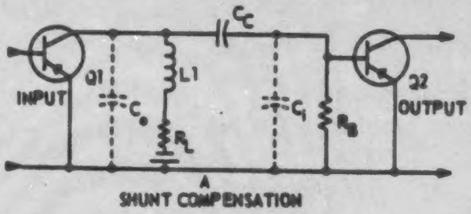
shows the limiting factor of such an amplifier. The low frequency response is limited by C_C. The reactance of C_C increases as frequency decreases.

Since C_C is in series, it drops more voltage at low frequencies leaving less to be applied as an input to Q2. High frequency response is limited by the dotted capacitances C_o and C_i. C_o represents the output and stray capacitance of Q1 and C_i is the input capacitance of Q2. As frequency increases, the reactance of C_o and C_i decrease, causing a loss of gain at high frequencies.

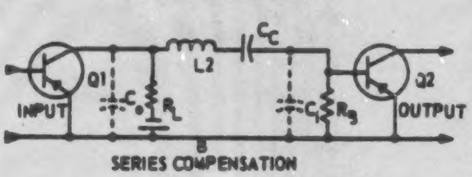
There are several ways to increase the frequency response of an amplifier so that it can process wideband signals successfully. One way is to decrease the size of the collector load resistor. This decreases the gain overall, but at the same time increases frequency response at both the high and low end of the band. A method of increasing the low frequency response is to increase the size of the coupling capacitor. Another way to increase low frequency response is to add a low frequency compensating network as shown in figure 39-3. R_F and C_F form a filter network which increases the gain at low frequencies only.

At high frequencies, C_F is nearly a short and neither it nor R_F is in the circuit. However, at low frequencies, C_F is a large reactance. This large reactance is in parallel with R_F and both are in series with R_L, which increases the collector load resistance and gain at low frequencies.

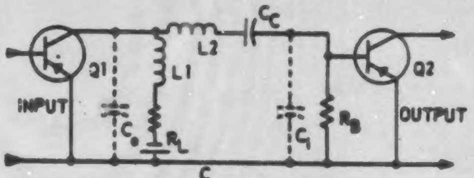
One way to increase high frequency response of an amplifier is through the use of shunt and series peaking coils. Figure 39-4 shows how these coils are placed in the circuit. L1 (figure A) is in shunt with the signal path and forms a parallel resonant circuit with C_o and C_i (C_C is a short at high frequencies). A characteristic of a parallel tank circuit is high impedance at resonance. Without L1, C_o provides a low impedance path to ground. With L1, the parallel tank is a high impedance and the gain at high frequencies is increased. L2 (figure B) is a series peaking coil. It is in series with the signal and forms a series resonant circuit with C_i (C_C is a short at high frequencies). The characteristics of a series tank circuit are low overall impedance at resonance, high current, and high voltage across either reactance. The series LC circuit causes a high voltage across C_i at high frequencies, and the gain at these frequencies is increased. Figure C shows the use of both series and shunt high frequency compensation.



A
SHUNT COMPENSATION



B
SERIES COMPENSATION



C
SERIES-SHUNT COMPENSATION

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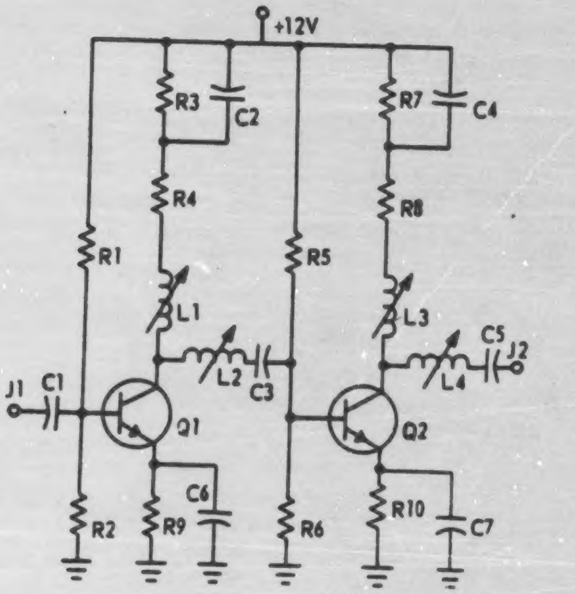
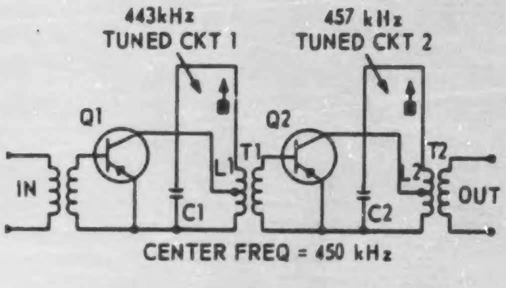
Figure 39-4. Wideband Amplifier, High Frequency Compensation


+12V
R3
C2
R7
C4
R4
R8
R1
R5
L1
L3
C5
J2
L2
C3
L4
J1
C1
Q1
Q2
C6
R2
R9
R6
R10
C7

REP4-1259

Figure 39-5. Compensated Wideband Amplifier

Figure 39-5 shows a fully compensated wideband amplifier. Collector loads R4 and R8 are small to increase overall frequency response. Coupling capacitor C1, C3, and C5 are large to increase low frequency response. Low frequency compensating networks R3-C2 and R7-C4 also increase low frequency response. Shunt peaking coils L1 and L3 and series peaking coils L2 and L4 increase high frequency response.

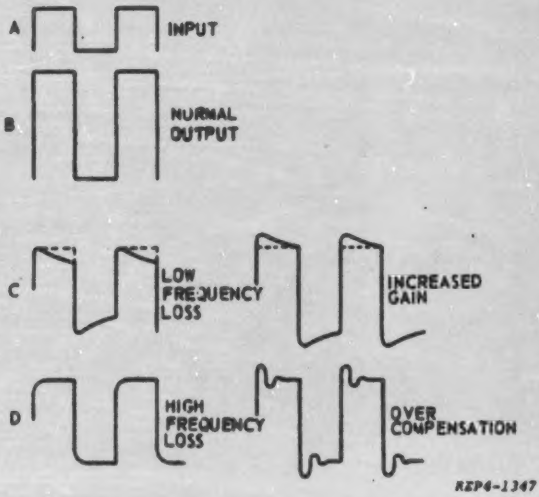

443kHz
TUNED CKT 1
457 kHz
TUNED CKT 2
Q1
Q2
T1
T2
IN
L1
L2
C1
C2
OUT
CENTER FREQ = 450 kHz

REP4-1258

Figure 39-6. Staggered Pair RF Amplifier (Simplified Schematic)

Another way to increase the bandwidth of amplifiers is through the use of STAGGER tuning. In this method, one transformer-coupled RF stage is tuned above the desired center frequency and the other is tuned below. The resultant bandwidth is greater than if each stage were tuned to the center frequency. Figure 39-6 is a simplified schematic of two stages set up for stagger tuning. The center frequency is 450 kHz. L1 and C1 are tuned to 443 kHz, and the output tank (L2-C2) is tuned to 457 kHz. The resultant bandwidth for both stages is greater than it would be if the tuned circuits were tuned to the center frequency.

In troubleshooting a two-stage, fully compensated wideband amplifier, we will discuss only those faults which could cause problems with either the low or high frequency gain of the circuit. The waveshapes shown in figure 39-7 indicate the results of shorted or opened frequency compensating components. Use figure 39-7 in conjunction with figure 39-5. Part A shows the square wave input and part B is the ideal amplified output. The first waveshape in part C is labeled LOW FREQUENCY LOSS and indicates a lack of gain at low frequencies. R3, R7, C2, or C4 could be shorted. The second wave in part C shows


A
INPUT
B
NORMAL OUTPUT
C
LOW FREQUENCY LOSS
INCREASED GAIN
D
HIGH FREQUENCY LOSS
OVER COMPENSATION

REP4-1347

Figure 39-7. Wideband Amplifier Waveforms

increased gain at high frequencies indicating C2 or C4 open. The first wave in part D is the result of a shorted peaking coil (L1, L2, L3, or L4). In many cases, the peaking coils are tunable and could be maladjusted. The results of maladjusted peaking coils are shown in the second waveshape in part D.

MODULE 40

SATURABLE REACTORS AND MAGNETIC AMPLIFIERS

Saturable reactors are inductors with special alloy cores. These cores can quicky saturate with a small magnetizing force, in either a positive or negative direction. When the core of an inductor goes from an unsaturated to saturated status, its impedance goes from a high to low level. A saturable reactor can be either a high or a low impedance and can change from one to the other (transient time) very rapidly. If a saturable reactor is placed in series with a load, it can control the amount of current delivered to the load. If the reactor's impedance is high, load current is small and if it is low, load current is high.

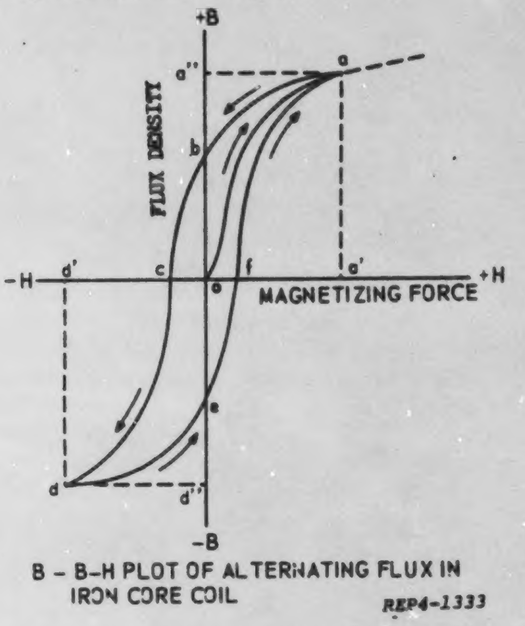


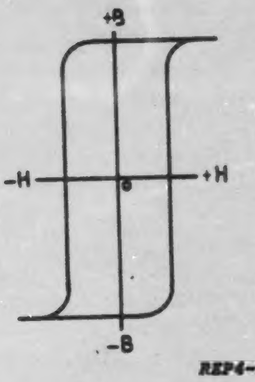
Figure 40-1. B-H Plot of Alternating Flux in Iron Core Coil

A magnetic amplifier is a circuit with a saturable reactor in series with a load and a method of controlling when and how long the reactor core is saturated. A DC winding on the reactor controls saturation and load current. It is an amplifier because a small current in the DC winding controls a large current in the AC winding.

The inductance of a coil is a direct function of permeability (mu) and coil impedance is directly related to inductance. Therefore, permeability controls the impedance of a coil. Permeability is a measure of the ability of a core material to act as a path for magnetic lines of force and is the ratio of flux density (B) to magnetizing force (H). Permeability (mu) is expressed as -

$$\mu(\text{mu}) = \frac{B}{H}\ .$$

A curve, called a **HYSTERESIS** loop shows the changes in permeability of a coil when an AC voltage is applied to it. Figure 40-1 shows the hysteresis loop for a coil with a soft iron core. As the magnetizing force (applied AC) starts to increase in a positive (+H) direction, flux density increases in the positive (+B) direction. Magnetizing force reaches maximum at point a' and flux density reaches maximum at point a''. As H decreases to zero, B also decreases, but does not reach zero (point b). The remaining flux is called **RESIDUAL** magnetism. When the magnetizing force is applied in the opposite direction, H must reach point C before B returns to zero. The force required to cancel the residual magnetism is called **COERCIVE** force. As H continues to increase to point d', flux density increases to point d''. The return of H to zero results in a reduction of B to point e and as before residual magnetism is left in the core. As H again goes positive it must reach point f before B returns to zero. The lagging of flux density behind magnetizing force is called hysteresis and actually represents a power loss. The area within the hysteresis loop is proportional to the amount of coercive force required to overcome the residual magnetism. The hysteresis loop for a coil with a soft iron core is not suitable for a saturable reactor because transient time



REP4-1334

Figure 40-2. Special Alloy Core

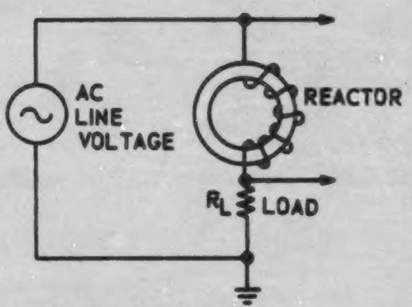
is too long. Figure 40-2 shows the ideal hysteresis loop for a saturable reactor. The special alloy core causes it to remain saturated until the coercive force cancels and reverses the direction of flux lines. This loop indicates that transient time is very low and not much force is required to saturate the core in either direction.

Figure 40-3A shows a simple saturable reactor circuit. It consists of a toroidal (ring) coil in series with a load resistor (R_L) and with an AC voltage applied.

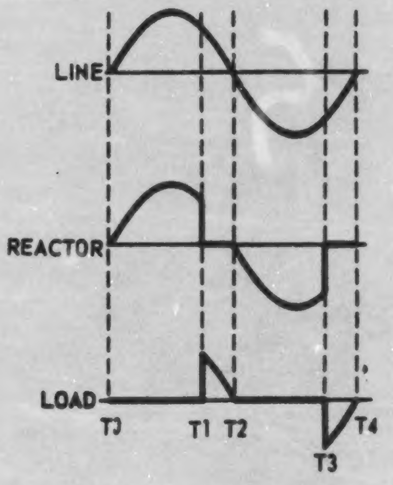
The reactor acts as a switch because its impedance is either very high (switch open) or almost zero (switch closed). Figure 40-3B shows how the switch operates to control load current and voltage. From time T_0 to T_1 the coil is not saturated and is a high impedance; therefore, no current flows through R_L. At T_1 the core saturates, coil impedance drops rapidly, and the line voltage appears across the load. The core remains saturated from T_1 to T_2 and load current flows. At T_2 the applied AC goes negative, the core is no longer saturated, and no line current flows. At T_3 the core again saturates and load current flows in the opposite direction.

The circuit just discussed is not a magnetic amplifier because there is no way to control core saturation and load current. Figure 40-4 shows how the control function is added. R_L is the load and the winding in series with R_L is the AC load winding. The other winding is for saturation control. Notice the control winding has DC applied through R_C. The DC current through the control winding sets the level at which the core saturates. The DC control current is determined by the setting of R_C. The greater the DC current, the quicker the core saturates when AC is applied. Figure 40-4C shows how the core saturation point changes for increasing values of control current.

You may see saturable reactor or magnetic amplifier circuits with provisions to



A. SIMPLE LOAD CIRCUIT



B. VOLTAGE WAVESHAPES

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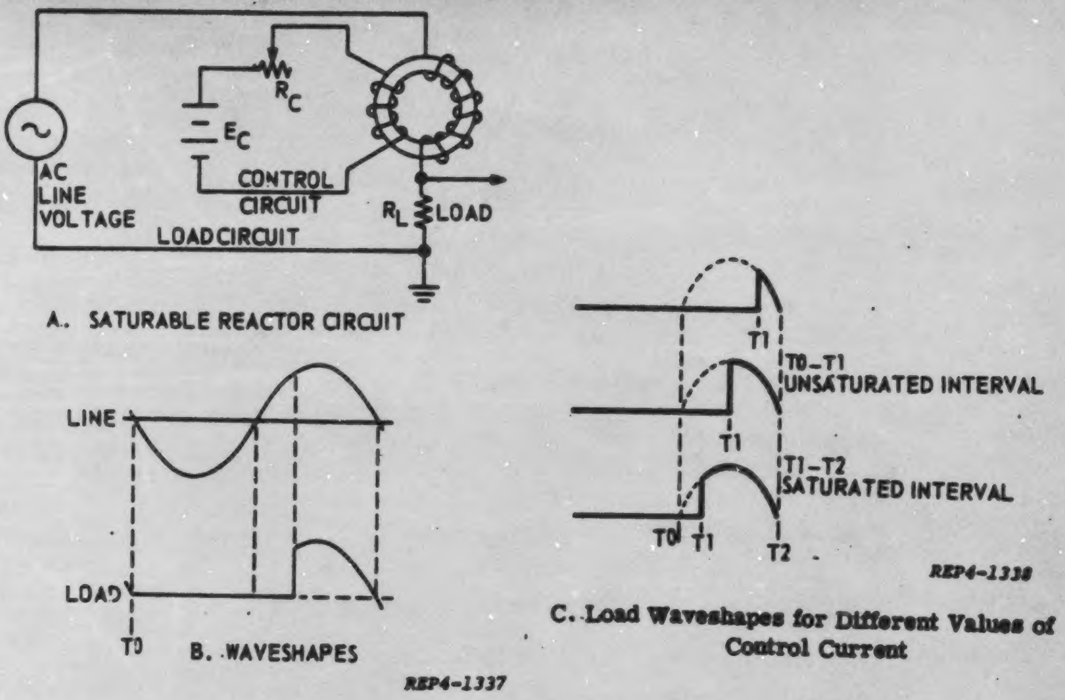
Figure 40-3. Saturable Reactor Simple Circuit



A. SATURABLE REACTOR CIRCUIT

B. WAVESHAPES

C. Load Waveshapes for Different Values of Control Current

Figure 40-4. Saturable Reactor with DC Control

prevent induced currents from the load winding from influencing control currents. This may be accomplished by the use of a high resistance control winding, addition of choke coils, twin core, three-legged, or twin-core common control windings. It is also quite common to see diodes placed in the AC output for rectification.

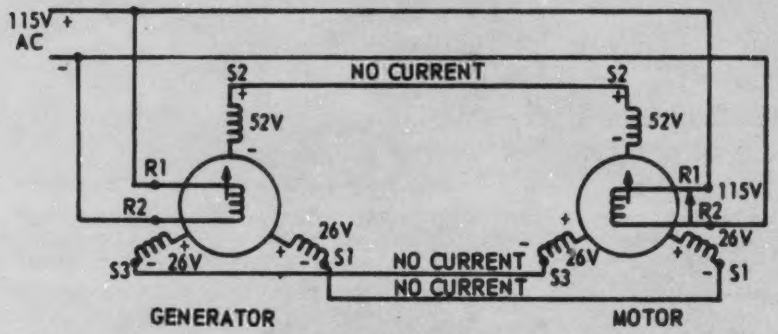
MODULE 41

SYNCHRO-SERVO SYSTEMS

The function of a synchro system is to couple a mechanical position to an indicating device, without mechanical linkage. The "mechanical position" is usually the position of a shaft and is called "angular position." In practice, a synchro is an inductive device capable of transforming an angular position input into an electrical output or an electrical input into an angular output. Synchro systems are used in many types of electronic equipment, such as radar, satellite tracking, bomb scoring, fire control systems and autopilots. Where small amounts of torque are needed to move heavy loads such as radar antennas and guns, a servo system is used. The purpose and function of synchro and servo systems are the same.

A synchro system consists of a synchro generator and synchro motor connected together electrically. The generator has a movable rotor and fixed stator. The rotor has an AC voltage applied to it but the stator does not. A voltage is induced into the stator-windings which are wound 120° apart. The generator stator windings are directly connected to the motor windings.

The motor stator winding has the same voltages as the generator stators if there


115V +
AC
-
S2
NO CURRENT
S2
+
52V
-
+
52V
-
R1
R2
R1
115V
R2
26V
S1
S3
- 26V
+
-
NO CURRENT
NO CURRENT
26V
S3
+
26V
-
S1
GENERATOR
MOTOR

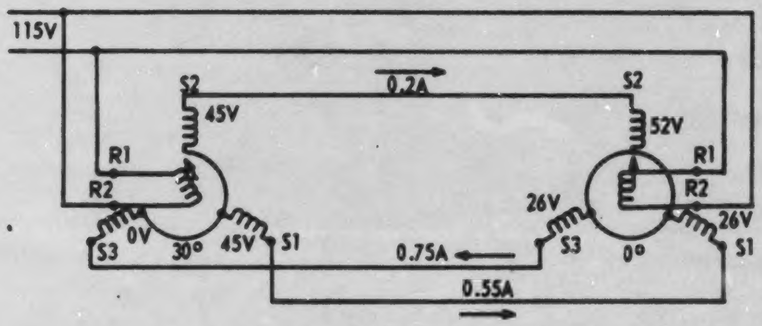
REP4-1361

Figure 41-1. Synchro Generator and Motor-No Angular Difference Between Rotors

is no angular difference between rotors. Figure 41-1 shows a properly connected synchro generator and motor. Slip rings are used to connect 115 VAC to the rotors of both the generator and motor. If the two rotors are aligned to the same angular position, the same voltages are induced into both sets of stator windings. This means that no current can flow between stator windings and no magnetic field exists to cause the motor rotor to turn.

If the generator rotor shaft is turned, a different situation exists as shown in figure 41-2. The generator rotor has been rotated 30°.

This causes the voltages induced into the generator stators to change. Now there is a difference of potential between the generator stators and the motor stators. This causes a current to flow, which sets up a magnetic field in the motor and causes the rotor to turn. When the motor rotor has reached the same position as the generator rotor, the voltages in the stator windings are again equal and the motor rotor stops turning. The rotor shaft of the motor is usually connected to some indicating device which always shows the position of the generator rotor. If the generator rotor turns continuously, the motor rotor will also turn continuously, but it will lag the generator by a small amount.


115V
S2
0.2A
S2
45V
52V
R1
R2
R1
R2
0V
30°
45V
S1
S3
26V
S3
0°
26V
S1
0.75A
0.55A

REP4-1362

Figure 41-2. Synchro Generator and Motor - 30° Difference in Rotor Shaft Positions

A synchro generator can be used to run several synchro motors. However, if too many motors are connected, excessive lag occurs and the accuracy of the whole system may be affected.

The basic purpose of a servo system is the same as that of a synchro system – to transmit angular information without mechanical linkage. Figure 41-3 is the block diagram of a servo system.

The input shaft, which might be connected to a hand control of some sort, is connected to the synchro generator rotor. The generator stator windings are electrically connected to the stator windings of a control transformer. A control transformer is a type of synchro which has both an electrical and mechanical input and an electrical output. The output shaft is mechanically connected to the control transformer rotor.

If there is any angular difference between the input and output shafts, the control transformer will generate an error. The amplitude and phase of the error voltage determines the speed and direction of rotation of the output shaft. The error voltage is applied to a servo power amplifier. The servo amplifier adds power to the error signal, which is then applied to one of the field coils of a two-phase induction motor. This causes the motor to turn and also causes the output shaft to turn. Suppose, for example, we turn the input shaft by 30°. This induces a voltage in the synchro generator stator windings and the control transformer stators cause an error voltage to be generated. The error voltage is amplified in the

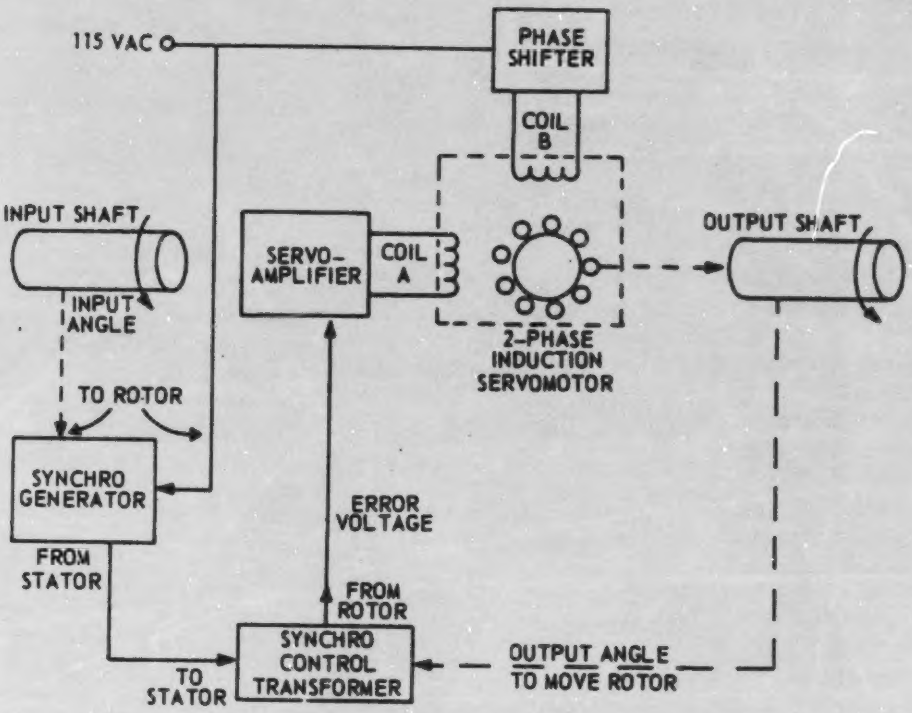

115 VAC
PHASE SHIFTER
COIL B
INPUT SHAFT
SERVO-AMPLIFIER
COIL A
OUTPUT SHAFT
INPUT ANGLE
2-PHASE INDUCTION SERVOMOTOR
TO ROTOR
SYNCHRO GENERATOR
ERROR VOLTAGE
FROM STATOR
FROM ROTOR
SYNCHRO CONTROL TRANSFORMER
TO STATOR
OUTPUT ANGLE TO MOVE ROTOR

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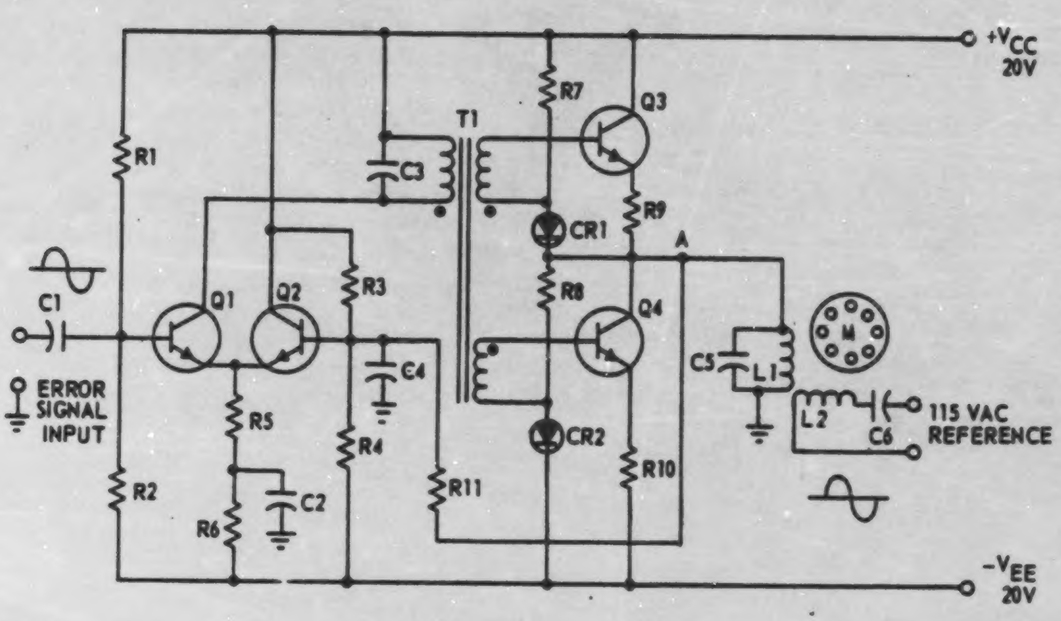
Figure 41-3. Servomechanisms with AC Servomotor



REP4-1373

Figure 41-4. Servoamplifier

servo amplifier and then applied to field coil A of the induction motor. This causes the motor to turn the output shaft toward the position of the input shaft. The error voltage becomes smaller and reaches zero when the output shaft position reaches that of the input shaft.

We said before that the servo amplifier adds power to the error signal. A typical servo amplifier is shown in figure 41-4.

This servo amplifier consists of two stages consisting of an error amplifier and a power amplifier. The error amplifier is made up of Q1 and Q2 and is connected as a differential amplifier. Q3 and Q4 make up a push-pull power amplifier. The output of the power amplifier is applied to L1, which is one of the field coils of an induction motor.

The error signal from the control transformer is applied to Q1 and amplified. the collector load for Q1 is the primary of T1. The amplified error signal appears across the primary of T1 and a voltage is induced into the split secondaries. The secondary of T1 splits the error signal into two voltages which are equal in amplitude and 180° out of phase. These signals are then applied to Q3 and Q4 which make up a standard push-pull amplifier. The diodes CR1 and CR2 in the forward bias network of Q1 and Q2 are temperature stabilization diodes. The output of the push-pull amplifier is applied to L1 and the motor turns as long as any error signal is present.

A portion of the output of the push-pull amplifier is connected from point A across feedback components R11 and C4 to the base of Q2. The feedback signal is in phase with the error signal at the base Q2, but lags it because of the time constant of C4 and R11. The feedback signal is coupled back to the emitter of Q1 by R5 and opposes the error signal. The net result is that Q1 amplifies the difference between the error signal and the lagging feedback signal. This fixes the gain of Q1 and prevents the load connected to the induction motor from oscillating when the error voltage reaches zero.

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Technical Training

Electronic Principles (Modular Self-Paced)

Volume V

SOLID STATE POWER SUPPLIES AND AMPLIFIERS

December 1975

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SOLID STATE POWER SUPPLIES AND AMPLIFIERS

This Student Text is the prime source of information for achieving the objectives of this block. This publication is designed for training purposes only and should not be used as a basis for job performance in the field.

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Chapter 1

SOLID STATE POWER SUPPLY RECTIFIERS AND FILTERS

1-1. The purpose of this text is to discuss solid state power supply RECTIFIERS and FILTERS. Rectifiers, generally, serve to convert AC voltage to a DC voltage for use in circuits where AC voltage is not acceptable. Filters serve to average the output DC pulses from the rectifiers and provide a constant amplitude DC voltage to those circuits. To see these two circuits in perspective, we must understand the functions of the other parts of a power supply. Let us first do a block diagram analysis of a typical power supply, and take special note of the functions of the rectifier and filter.

1-2. THE POWER SUPPLY

1-3. The power supply is an electronic unit used to convert one form of electrical power. A power supply can be constructed to convert AC power to DC power, or a small DC to a large DC. The amount of power produced by the power supply must meet the load requirements of the circuit it serves.

1-4. Figure 1-1 is a block diagram of a power supply. The blocks represent the individual circuits within the power supply, and the arrows show the path the current takes through the circuits. The input voltage is applied to the TRANSFORMER, which is capable of stepping up or stepping down the voltage to the required level for the circuit being supplied. The amount of voltage from the transformer is determined by the voltage input to it and the type transformer being used. Thus the transformer in a power supply is used to provide the correct amplitude of voltage needed for the particular circuit being used. The voltage output from the transformer is then applied to a RECTIFIER. The purpose of the rectifier is to change the AC voltage to DC voltage. The DC output from the rectifier is constantly changing in amplitude, being in the form of pulses; this output voltage is referred to as a pulsating DC voltage. The pulsating DC cannot be applied to the amplifiers and obtain satisfactory operation. This output voltage must be changed to a constant amplitude DC. This is accomplished by the next circuit in the block diagram, the FILTER. However, even the output from the filter can change due to changes in input voltage, or in the amount of current drawn from the power supply. To compensate for these variations, we use a VOLTAGE REGULATOR to maintain or regulate the output voltage to the critical level needed. Methods of regulating this voltage will be discussed later. The last circuit in the power supply is the VOLTAGE DIVIDER. It's function is to provide the output voltages which are required for the amplifier's bias and collector supply voltages.

1-5. Now that you've seen the function of the power supply, let's discuss each of these circuits in greater detail.

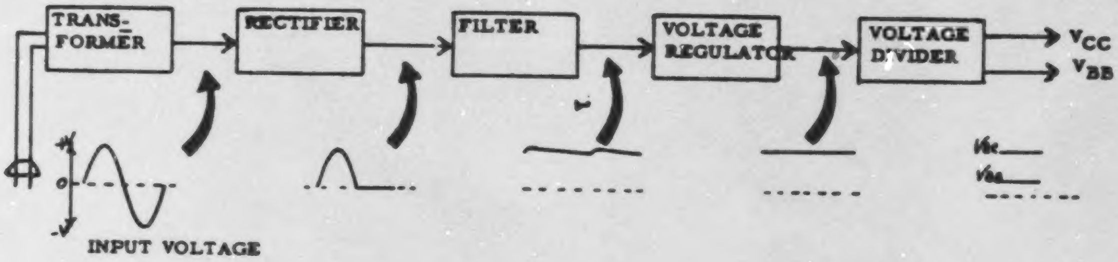

Figure 1-1. AC to DC Power Supply Block Diagram

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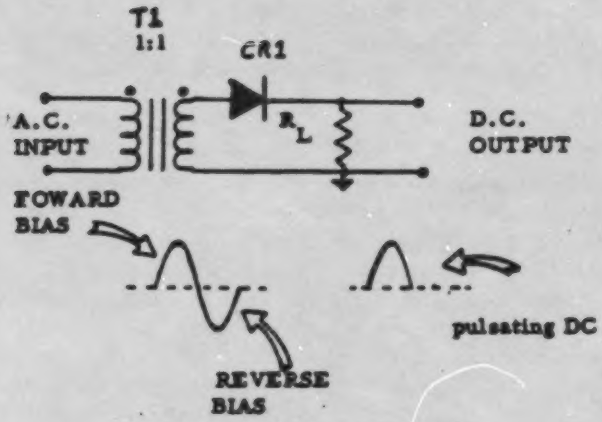

T1
1:1
CR1
A.C.
INPUT
R_L
D.C.
OUTPUT
FOWARD
BIAS
REVERSE
BIAS
pulsating DC

Figure 1-2. Half-Wave Rectifier

1-6. HALF-WAVE RECTIFIER

1-7. In Figure 1-1, we see that the input to the rectifier is the output from a transformer. However, the transformer is only required if we want to change the level of voltage applied to the rectifier. If the power supply is required to furnish a high voltage output, a step-up transformer is used. For transistorized equipment, a low voltage is used, therefore, a step-down transformer is employed. If no change in voltage level is needed, the input can be applied directly to the rectifier. However, this practice makes the power supply output common to the AC input and presents a safety hazard to both equipment and maintenance men. For this reason, a one-to-one transformer is used for isolation of the power supply output from the AC input.

1-8. Figure 1-2 shows the schematic diagram for a half wave rectifier. It is one of several rectifier circuits you will analyze. It's purpose is to change the AC output from the transformer to direct current.

1-9. As you recall, when forward bias is applied to a PN junction diode, it's resistance decreases and allows majority current to flow. When the junction diode is reverse biased, it's barrier width is very large and we have no majority current flow. A diode placed in series with an AC source and a load resistor will have forward and reverse bias applied with every cycle. Since the diode will allow current flow in only one direction, we have direct current in the output and rectification has been accomplished.

1-10. In figure 1-2, transformer T1 supplies the AC to the rectifier diode CR1. T1 is an

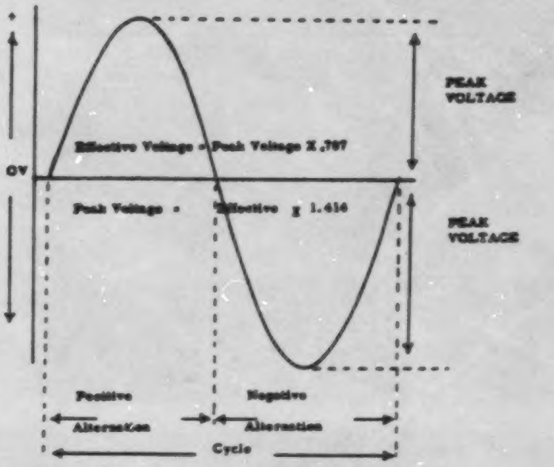

+
OV
PEAK
VOLTAGE
PEAK
VOLTAGE
Effective Voltage = Peak Voltage X .707
Peak Voltage = Effective x 1.416
Positive
Alternation
Negative
Alternation
Cycle

Figure 1-3. Sine Wave Characteristics

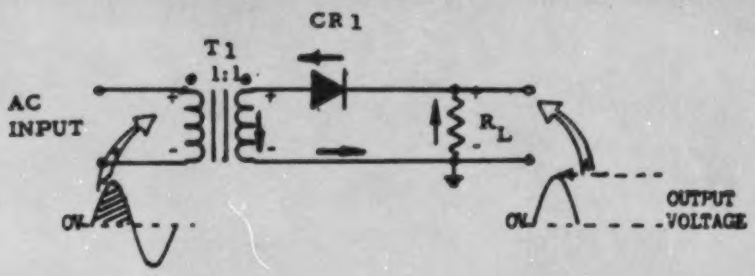


Figure 1-4. Half-Wave Rectifier, Positive Alternation Input

isolation transformer as indicated by the 1 to 1 turns ratio. T1 also has "phasing dots" located on the top side of primary and secondary windings. The phasing dots indicate that the polarity of the voltage at these points will be the same. Resistor R_L is the load resistor and represents all of the circuits which will draw current from the rectifier.

1-11. The amount of current that R_L will allow to flow in the circuit is called the "load." If the resistance of R_L is small, it will allow a large current flow. The circuit is then said to have a large or "heavy" load. A small or "light" load is placed on the circuit if R_L is large.

1-12. Since an alternating voltage is applied to the rectifier, let's review some terms associated with AC. Figure 1-3 shows a SINE WAVE and some terms that should be familiar to you.

1-13. The maximum amplitude of the wave in either the positive or negative alternation is the PEAK of the wave. This can be observed and measured with an oscilloscope. The EFFECTIVE voltage is the measured voltage using an AC meter. Both voltages can be calculated as shown in Figure 1-3.

1-14. Figure 1-4 illustrates circuit operation of a half-wave rectifier. Let's assume that the polarity of the voltage at the top of T1 primary is positive with respect to the bottom side. The phasing dots indicate that the top of T1 secondary would also be positive with respect to ground. This secondary voltage is forward bias for the diode. The resistance of the forward biased diode would be low and current will flow through the circuit in the direction of the arrows. Current flow through the load resistor (R_L) develops the voltage as shown during the positive half of the AC input signal.

1-15. When the AC input goes through the negative alternation as shown in Figure 1-5,

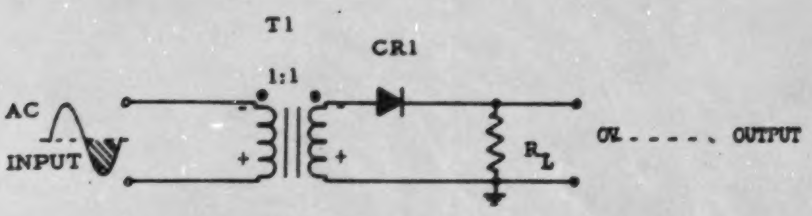


Figure 1-5. Half-Wave Rectifier, Negative Alternation Input

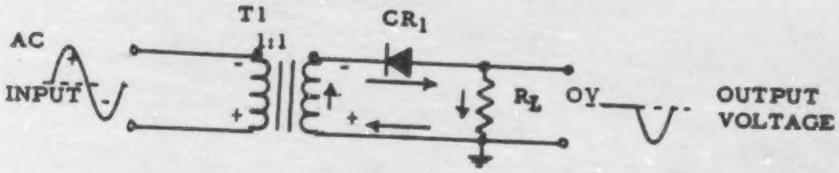


Figure 1-6. Half-Wave Negative Rectifier

the top of T1 secondary becomes negative with respect to ground. This negative voltage reverse biases the diode and it's resistance becomes very high. Majority current flow ceases and only a very small minority current will flow. For all practical purposes, there is no voltage developed across the load resistor. This circuit is called a half-wave rectifier, because current flows during half of the input wave.

1-16. The circuit in Figures 1-4 and 1-5 are designed to produce a positive voltage output. If negative voltages are required, (when using PNP transistors as an example) the diode can be reversed causing current flow to reverse. Refer to Figure 1-6, notice that current flows during the negative alternation and it's direction produces a negative voltage at the output.

1-17. Now that we have seen how current flows and how an output is developed in the half wave rectifier, let's apply an input signal voltage of definite values. Figure 1-7 shows the half-wave rectifier with 200 VAC as the input voltage. This is the measured or effective value of AC. Notice that the secondary voltage is 282 volts peak (200V EFF x 1.414) and the output voltage pulse is 282 volts peak. We disregard the small voltage drop across the diode in all our calculations. The voltage peak across R_L can be measured with an oscilloscope. However, when measuring the voltage across R_L using a DC multimeter, the DC average is read. The average output voltage during one half cycle (output pulse) is .318 times the peak output voltage. The average for an AC sine wave (1 full cycle) is .636 x peak. Since the half-wave rectifier produces only one half

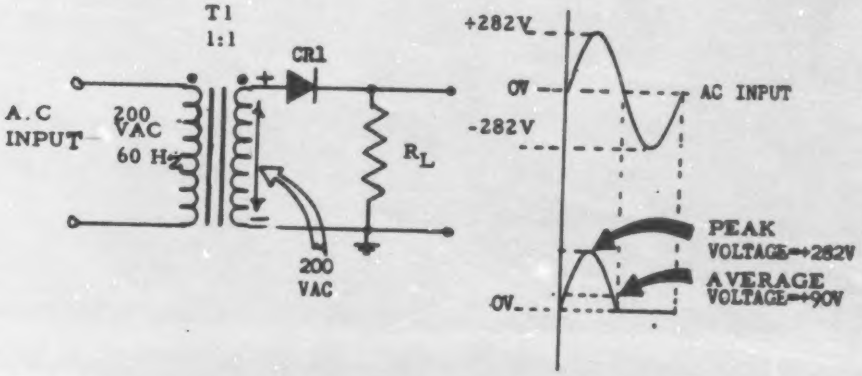


Figure 1-7. Half-Wave Rectifier

cycle in it's output, the average output voltage becomes the average of one alternation instead of two. Therefore, the average output voltage is 90 volts (282 volts peak x .318).

1-18. On the negative alternation, the diode does not conduct due to the reverse bias applied to it. The reverse voltage applied to the diode has a peak voltage of 282.8 volts (secondary voltage) and is called the "peak inverse voltage" (PIV). You will recall that a diode can stand only so much voltage in the reverse direction before it will break down. By knowing the peak inverse voltage of the circuit, you can select a diode that has a breakdown rating that exceeds the peak inverse voltage (PIV).

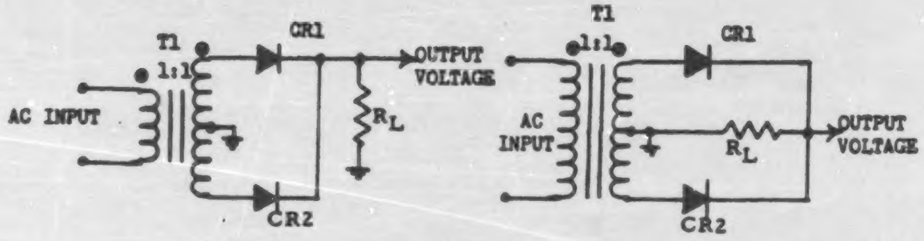
1-19. The output voltage of the half-wave rectifier is in the form of pulses. You will note in Figure 1-7, that we get 1 pulse of output voltage for 1 cycle of input voltage. The frequency of the pulses is therefore controlled by the frequency of the input voltage. The frequency of a rectifier output is given in pulses-per-second (PPS) and is called the RIPPLE FREQUENCY. In figure 1-7, the input frequency is 60 Hertz (60 Hz) and the output ripple frequency is 60 pulses-per-second (60 PPS). Note that the output voltage from the circuit changes from 0 volts to a peak of 282 volts. This minimum to maximum voltage change (peak to peak) is called the RIPPLE AMPLITUDE.

The higher the ripple amplitude of the output voltage, the more difficult it will be to change to a constant DC which is required as an output from a power supply. Figure 1-8 gives a summary of the half-wave rectifier.

1-20. The characteristics of the half-wave rectifier, as compared to other rectifiers, will be shown in figure 1-16.

Input Voltage	Input Frequency	Peak Output Voltage	Average Output Voltage	Ripple Amplitude	Ripple Frequency	Peak Inverse Voltage
200 V AC	60 Hz	282 V	90 V DC	282 V	60 PPS	282 V

Figure 1-8. Half-Wave Rectifier Summary


T1
1:1
CR1
OUTPUT VOLTAGE
AC INPUT
R_L
CR2
T1
1:1
CR1
AC INPUT
R_L
OUTPUT VOLTAGE
CR2

9A

9B

Figure 1-9. Full-Wave Rectifier

1-21. FULL-WAVE RECTIFIER

1-22. The full-wave rectifier is shown in Figure 1-9. The identifying features of the full-wave rectifier are: Two diodes CR1 and CR2, a center-tapped transformer and a load resistor (R_L). The full-wave rectifier is basically two half-wave rectifiers as shown in Figure 1-9B.

This arrangement is used to produce an output voltage pulse for each alternation of the. input cycle.

1-23. Figure 1-10 shows the full-wave rectifier, in its simplified form, with an input signal voltage applied. Note that the center tapped transformer divides the secondary voltage into 2 equal parts which are opposite in polarity with respect to ground or the tap. CR1 is forward biased while CR2 is reverse biased. Current will flow in the circuit as shown, developing a voltage across R_L which is positive with respect to ground. Since the input voltage to CR1 and R_L is 141 volts peak, this is the voltage which is developed across the load resistor. We ignore the small voltage which is present across CR1. The ripple or peak-to-peak amplitude of the output is 141 volts. With the same input voltage, the full wave rectifier has a ripple amplitude which is only one-half that of the half-wave rectifier. Notice that the peak output voltage is only

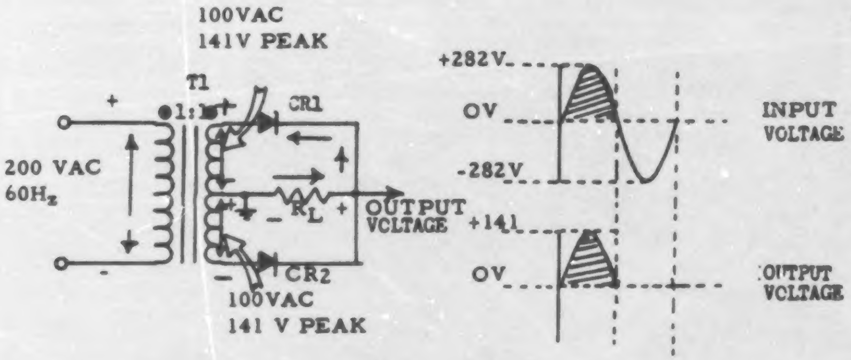

100VAC
141V PEAK
T1
1:1
CR1
+
-
200 VAC
60Hz
R_L
OUTPUT VOLTAGE
CR2
100VAC
141 V PEAK
+282V
OV
-282V
INPUT VOLTAGE
+141
OV
OUTPUT VOLTAGE

Figure 1-10. Full-Wave Rectifier Positive Alternation Input

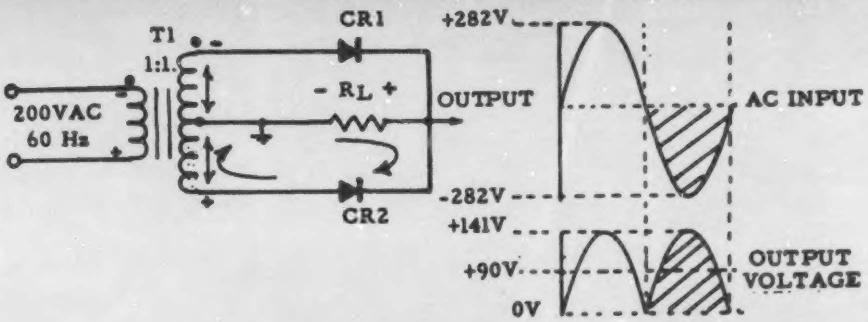


Figure 1-11. Full-Wave Rectifier, Negative Alternation

one-half of the peak input voltage because of the tapped transformer. During the positive alternation of the input voltage, CR2 is reverse biased and has a peak inverse voltage (PIV) of 282 volts. The anode of CR2 is connected to the bottom side of T1 (-141 V) and it's cathode is connected through CR1 to the top of T1 (+141 V). Since CR1 is conducting, it's resistance and voltage drop are so small that we can ignore them.

1-24. During the negative alternation, the input voltage polarities would change as indicated in Figure 1-11.

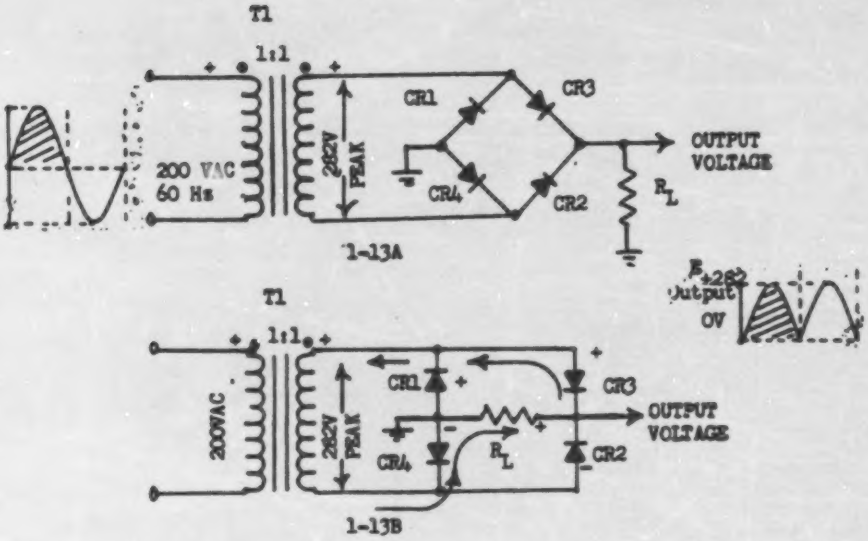
CR1 is now reverse biased and CR2 is forward biased. Note that current flowing through CR2 and R_L will develop a positive voltage across R_L with respect to ground. The current through R_L flows in the same direction for both alternations of the input signal producing two output pulses of the same polarity. The polarity of the output pulses can be changed by reversing both diodes causing current through R_L to reverse. Therefore, reversing the output voltage polarity.

1-25. In the full wave rectifier, we produce two pulses for every cycle of input voltage. The ripple frequency then is two times the input frequency. In Figure 1-11, the input frequency is 60 Hertz (60 Hz) and the ripple frequency is 120 pulses-per-second (120 PPS).

1-26. Since the output from a full-wave rectifier contains two pulses for every cycle,

Input Voltage	Input Frequency	Peak Output Voltage	Average Output Voltage	Ripple Amplitude	Ripple Frequency	PIV
200 VAC	60 Hz	141 V	90 VDC	141 V	120 PPS	282 V

Figure 1-12. Full-Wave Rectifier Summary


T1
1:1
+
+
200 VAC
60 Hz
282V PEAK
CR1
CR3
CR4
CR2
OUTPUT VOLTAGE
R_L
E +282
Output
0V
200VAC
OUTPUT VOLTAGE

1-13A

1-13B

Figure 1-13. Bridge Rectifier Positive Alternation Input

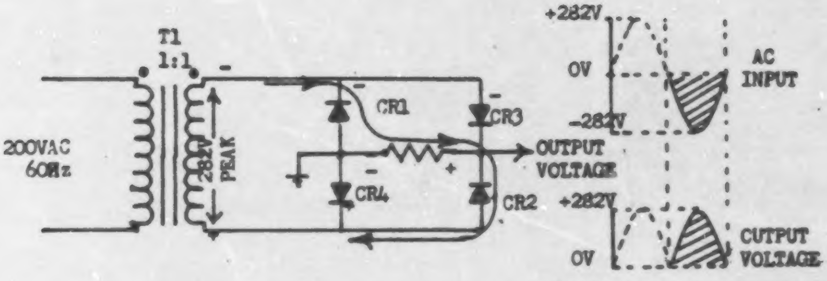

T1
1:1
-
200VAC
60Hz
282V PEAK
CR1
CR3
CR4
CR2
OUTPUT VOLTAGE
+282V
0V
-282V
AC INPUT
+282V
0V
OUTPUT VOLTAGE

Figure 1-14. Bridge Rectifier Negative Alternation Input

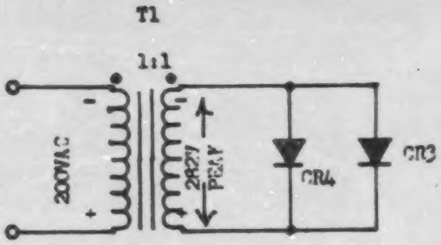


Figure 1-15. Bridge Rectifier Peak Inverse Voltage

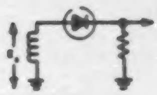
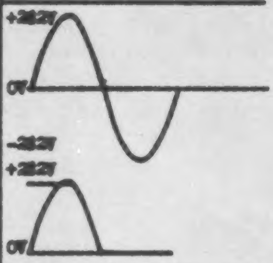
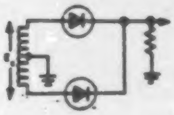
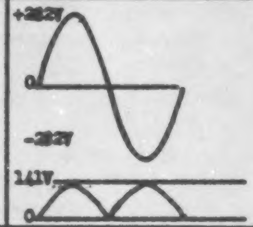
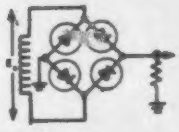
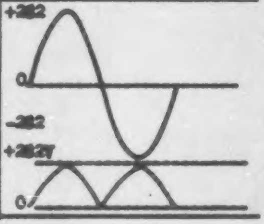
	Input Voltage And Frequency	Peak Output Voltage	Average Output Voltage	Ripple Amplitude	Ripple Frequency	Peak Inverse Voltage	WAVEFORM
 HALF-WAVE RECTIFIER	200VAC 60Hz	282V (RMS X 1.414)	90VDC (Peak X .318)	282V	60 PPS	282V	
 FULL-WAVE RECTIFIER	200VAC 60Hz	141V	90VDC (Peak X .636)	141V	120 PPS	282V	
 BRIDGE RECTIFIER	200VAC 60Hz	282V	180VDC (Peak X .636)	282V	120 PPS	282V	

Figure 1-16. Rectifier Summary

the average output voltage can be calculated as follows:

Average voltage = peak output voltage x .636. The average output voltage from the full-wave rectifier in Figure 1-11 is 141 volts peak x .636 =90 volts average. Figure 1-12 gives the summary for a full-wave rectifier.

Notice that the full-wave rectifier produces a lower ripple amplitude than the half-wave rectifier.

1-27. This lower ripple amplitude is easier to filter or change to a constant DC. Comparing the ripple frequency, we find that the full wave has a higher ripple frequency. This will also enable the rectifier output to be filtered more easily.

1-28. BRIDGE RECTIFIER

1-29. The bridge rectifier is a modification of the full-wave rectifier. Note that a center-tapped transformer is not used. However, it requires four diodes. Refer to Figure 1-13 for the analysis of the bridge rectifier. Figure 1-13B is a re-drawn version of the bridge rectifier. During the positive alternation, the diodes CR3 and CR4 are forward biased while CR1 and CR2 are reverse biased. Current flow through the circuit would develop an output voltage across R_L. The peak output voltage across R_L is equal to the peak voltage of the transformer secondary.

1-30. With the negative alternation input, the conditions in Figure 1-14 would exist. The conducting diodes have changed but the current through R_L is in the same direction. For each alternation, two diodes are in the current path.

1-31. The bridge rectifier produces two pulses output for every input cycle. The ripple frequency of the output in Figure 1-14 is 120 PPS.

1-32. Since both alternations of the input cycle produce a pulse in the output, the average output voltage is 180 volts (282 V Peak x .636.)

1-33. To illustrate peak inverse voltage, refer to Figure 1-15. When CR1 and CR2 are conducting, they have a low resistance and can be considered shorts. Therefore, CR3 and CR4 are connected across the transformer secondary and the PIV is equal to the peak voltage of the secondary.

1-34. Figure 1-16 gives a summary of the half-wave, full-wave, and bridge rectifiers.

1-35. THREE-PHASE RECTIFIER

1-36. When large amounts of power are required from a rectifier, a three-phase rectifier may be used instead of the single-phase. The generator used to supply this power produces 3 single-phase voltages that have a phase angle of 120° between phases. The transformer used in a three-phase rectifier must have 3 inputs, one for each phase. The transformer windings may be connected in one of two configurations called "Delta" or Wye."

1-37. Figure 1-17 illustrates a 3-phase transformer in a delta-to-wye configuration.

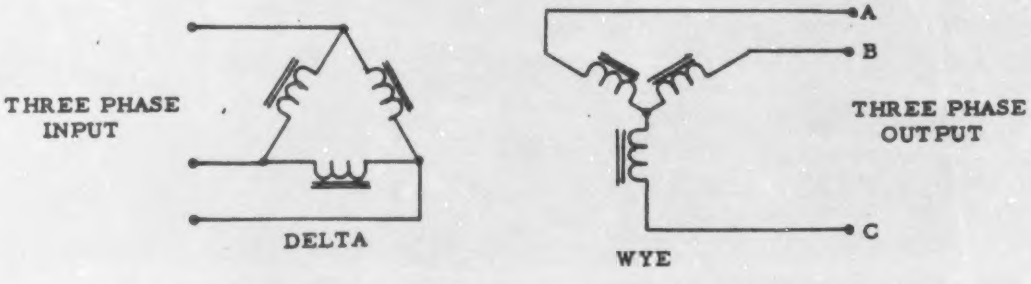


Figure 1-17. 3 Phase Transformer Delta to Wye

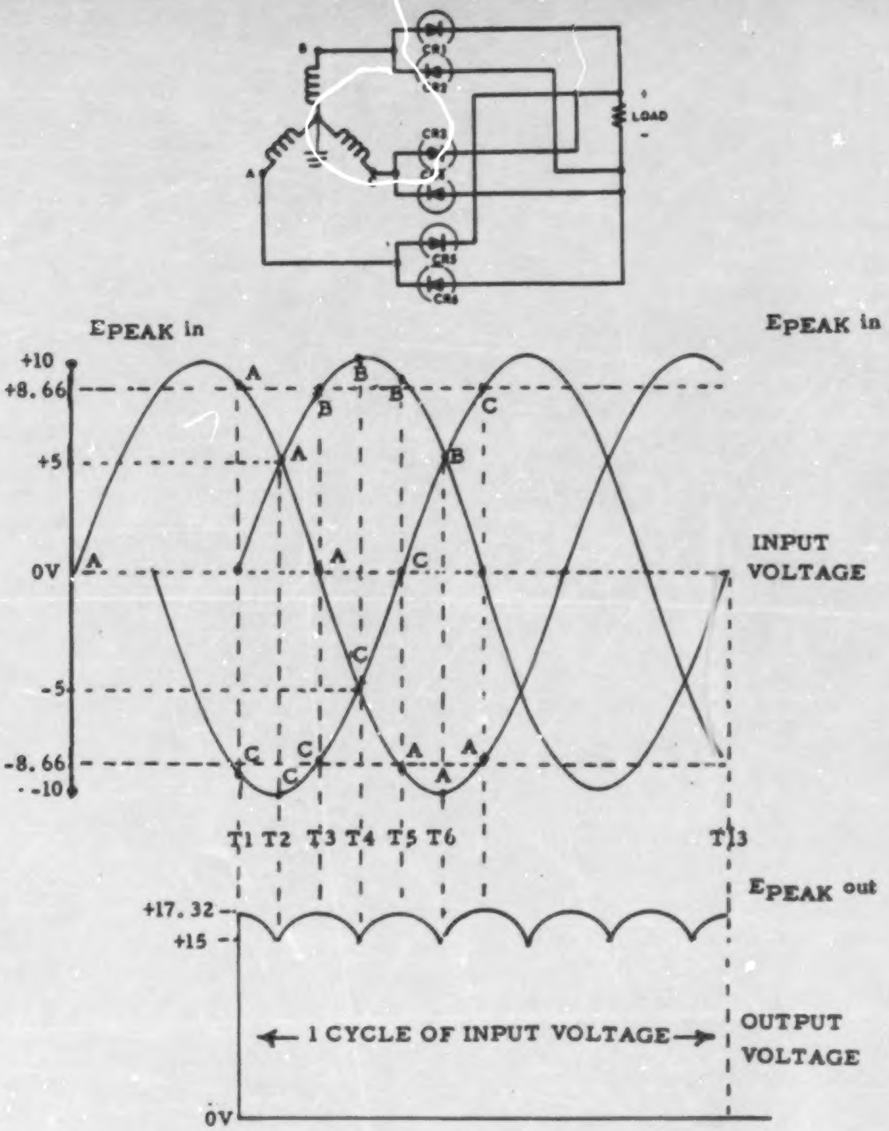
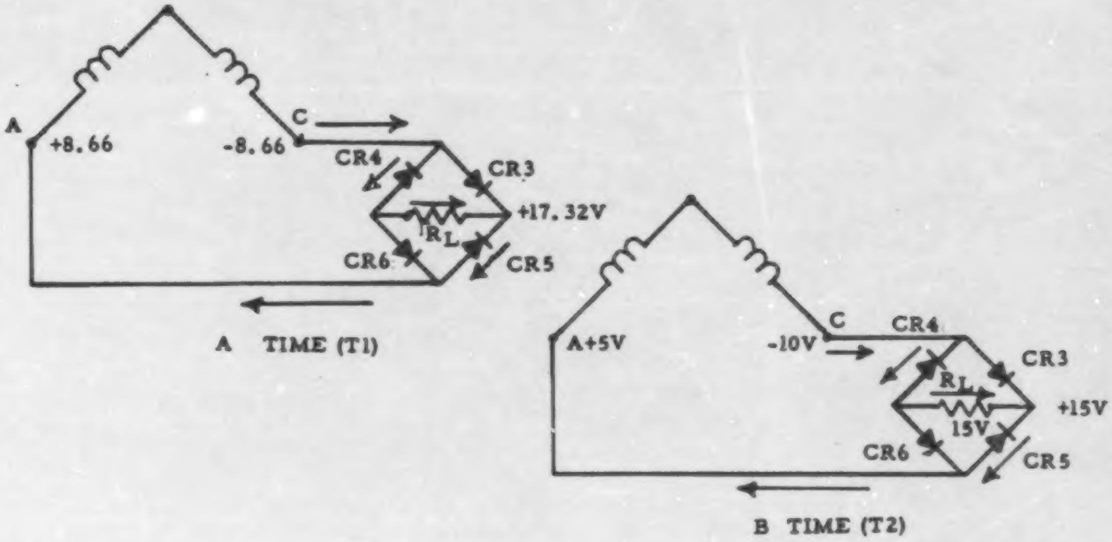

B
A
CR1
CR2
CR3
CR4
CR5
CR6
+
LOAD
-
EPEAK in
EPEAK in
+10
+8.66
+5
0V
-5
-8.66
-10
A
B
C
INPUT VOLTAGE
T1 T2 T3 T4 T5 T6
T13
EPEAK out
+17.32
+15
1 CYCLE OF INPUT VOLTAGE
OUTPUT VOLTAGE
0V

Figure 1-18. Three Phase Rectifier with Input and Output Voltage Waveforms

Assuming equal turns with primary and secondary windings, a delta-wound primary with a wye-wound secondary increases the voltage from primary to secondary (A to C, A to B, or B to C) by a factor of 1.732 to 1. Reversing the arrangement (wye primary, delta secondary) results in a current increase of 1.732 to 1. Three-phase voltages can be rectified by a three-phase bridge-type rectifier. Figure 1-18 shows a three-phase bridge rectifier with its three-phase input voltages and output voltage waveforms. Note that the three-phase input voltages are labeled phase A, B, and C and are 120° out of phase with each other. The three-phase voltages are also indicated on the transformer secondary. For purposes of discussion, we will assume that the input voltage to one leg of the secondary is 10 volts peak. From the formula we can determine that E_{pk} out is equal to 1.732 x E_{pk} in or 17.32 volts as indicated in Figure 1-18.



A TIME (T1)

B TIME (T2)

Figure 1-19. Three Phase Rectifier

If the input AC voltage were given in effect value, then we would need to multiply by 1.414 to obtain the peak value. Then multiply this peak value by 1.732 to obtain E_{pk} out. This is the same as 2.45 x $E_{effective}$. Recall that to convert E_{pk} to $E_{effective}$ we need to multiply by .707. Thus, $10V_{pk}$ x .707 = 7.07 VAC and 7.07 VAC x 2.45 = 17.32 E_{pk} out.

1-38. To analyze circuit operation, we will look at the three-phase voltages and polarities at various times during the cycle of input voltages. At time T1 in Figure 1-18, note that phase A is positive 8.66 volts, phase B is zero volts and phase C is negative 8.66 volts. The equivalent circuit at this time is shown in Figure 1-19A. The peak output voltage across R_L is 17.32 volts as indicated on the output waveform in Figure 1-18.

In our discussion of the three-phase rectifier, only two of the three "legs" or phases are used at any one time to determine the output voltage. In reality, however, all three phases provide a vector sum output voltage. Circuit operation would be equivalent to the discussion which follows on the three-phase rectifier. Therefore, at time T2, we will assume that phases A and C are used (Figure 1-19B). Since phases A and B at time T2 are of the same amplitude and polarity, the output voltage would be the same regardless of which phase is used. At time T2 phase A is positive 5 volts and phase C is negative 10 volts. In Figure 1-19B, it can be seen that the output voltage across R_L would decrease to 15 volts.

1-39. At time T3 we find that phase A is zero volts, phase B is positive 8.66 volts and phase C is negative 8.66 volts. Figure 1-20 shows the equivalent circuit at T3. Notice that the diodes used in the bridge rectifier have changed and the output rises to 17.32 volts which is the difference between phases B and C.

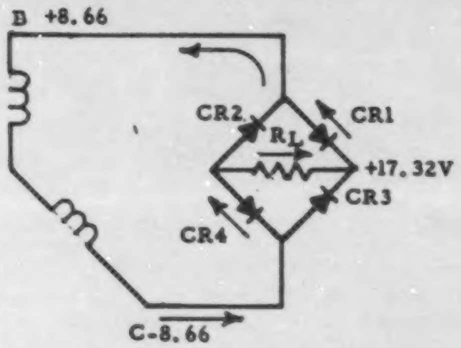


Figure 1-20. Three Phase Rectifier at Time T3

1-40. At time T4, phase B and C are still used but the output voltage drops to 15 volts. The difference between phase B and C voltages is only 15 volts at this time.

1-41. At time T5 the diodes used are once again changed and the circuit is shown in Figure 1-21. The output voltage rises to 17.32 volts when phase B is positive 8.66 volts and phase A is negative 8.66 volts. At T6 the difference between phases A and B drops to 15 volts and the output will also be 15 volts.

1-42. At time T7 the phases A and C are used once again as shown in Figure 1-19 with one exception, the polarity of the phases have changed. Phase A becomes -8.66 volts and phase C becomes +8.66 volts. The direction of current flow through the diodes will change. However, the current through the load resistor (R_L) will not. Therefore, the voltage will still be positive and will be 17.32 volts.

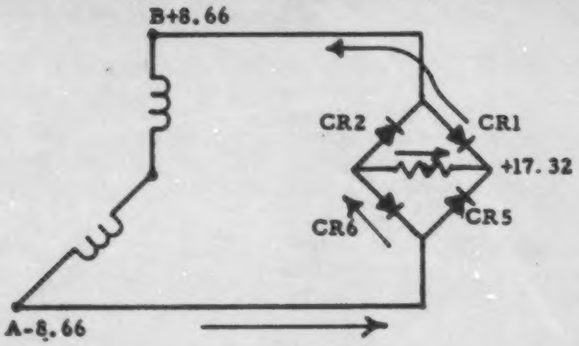


Figure 1-21. Three Phase Rectifier at Time T5

1-43. Notice that between T1 and T13 in Figure 1-18 we have 1 complete cycle of input voltage and 6 output voltage pulses. The ripple frequency therefore is six times the input frequency. Note also that the output ripple amplitude is only 2.32 volts in our example used (17.32 volts max - 15 volts min). The ripple amplitude is 13.4 percent of the output voltage amplitude. From this

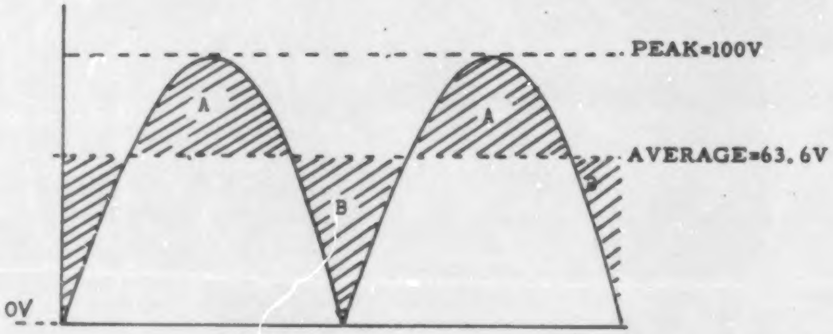


Figure 1-22. Ripple Voltage Or AC Component

we can conclude that the 3 phase rectifier output can be converted to a constant voltage much more easily than the half-wave, full-wave bridge rectifiers. This is due to the lower ripple amplitude and higher ripple frequency.

1-44. FILTERS

1-45. In our discussion of power supplies, we have seen how the transformer and rectifier circuits function. The output from the rectifier circuit was a pulsating DC which is not acceptable for the operation of most electronic equipment. Properly designed filters are used to convert pulsating DC to a constant DC. The purpose of the filter is to reduce the ripple amplitude of the rectifier output. The ripple amplitude was defined as the peak-tc-peak change in the rectifier output voltage. Now, let's discuss ripple voltage in relationship to the average output voltage.

1-46. The unfiltered output of a full wave rectifier is shown in figure 1-22. The polarity of the output voltage does not reverse, but its magnitude fluctuates above and below an average value. Note that the average voltage is shown as the line that divides the waveform so that area A equals area B. The fluctuation of the voltage above and below this average value is called the "ripple" or "AC component" of the rectified output. The amplitude of the ripple is 100 volts peak-to-peak. The output of any rectifier therefore has a ripple because its output is in the form of pulses. For most applications, ripple voltage amplitude must be decreased to a very low value. This is done by the filter circuit.

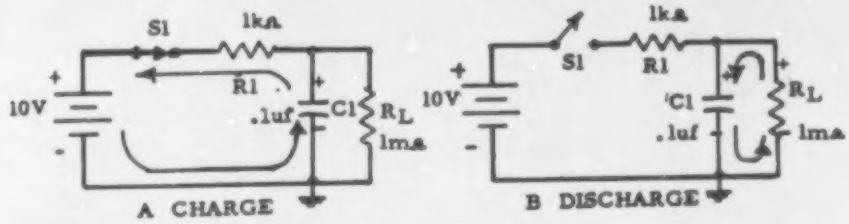
2-1. CAPACITIVE FILTER

2-2. The first of several filters we will discuss is the capacitive filter. As you recall from your lessons on capacitors, they will store energy or voltage when a voltage is applied. When the voltage applied is removed, it will supply energy back into the circuit. To review this action, refer to figure 2-1.

When S1 is closed in figure 2-1A, the capacitor will charge through R1, S1, and the battery. The length of time that it will take C1 to fully charge to the applied voltage of 10 volts is five time constants. One time constant is equal to R1 times C1 (TC=RC) and is 100 microseconds with the values shown in figure 2-1A. For the capacitor to fully charge, it will take five time constants or in our example 500 microseconds (.5 milliseconds).

2-3. When S1 is opened the capacitor will discharge returning the energy back to the circuit. It's only path for discharge is through the load resistance and will require 5 time constants to completely discharge. One discharge time constant is determined by C1 and R_L, and is equal to 100 milliseconds (.1 seconds). Note that C1 takes 1000 times longer to discharge than it does to charge. It is this circuit characteristic which is used in a filter circuit to oppose changes in rectifier output voltage or ripple voltage. In figure 2-2A note that the battery has been replaced by the transformer and the switch S1 by the diode rectifier CR1.

2-4. The positive input signal will cause CR1 to conduct, current will flow through the load resistor R_L, and the output voltage will rise to 100V as shown in figure 2-2C. During the time from T0 to T1, C1 will charge very rapidly to the peak of the input voltage. The charge path is shown in figure 2-2A. At time T1, the input voltage to CR1 will start to decrease from its peak value of 100V. The cathode of CR1 is positive 100V with respect to ground (voltage across C1). When the voltage applied to the anode decreases below 100V, CR1 will be reverse biased and will stop conducting. C1 will start discharging at time T1 and the output voltage across R_L will slowly decrease as C1 discharges through it. C1 continues to discharge from T1 to T2 time. At T2 time, the input voltage applied to the anode of CR1 becomes greater than the voltage on C1. CR1 will conduct and the current through C1 will rapidly recharge it to the peak input voltage. At T3 time, the diode will once again stop conducting and C1 will supply discharge current through the load resistance. It can be seen that the amount of voltage change across R_L is dependent upon how long C1 is allowed to discharge. If the discharge time constant is large, C1 will discharge slowly and the output voltage will change only a small amount. Remember, the peak-to-peak changes are ripple amplitude or ripple voltage. In the example in figure 2-2 the output voltage changes from 100 volts to 60 volts or a 40 volts peak-to-peak ripple voltage. Since the discharge time constant for the filter C1 is dependent upon its value



A CHARGE

B DISCHARGE

Figure 2-1. RC Time Constants

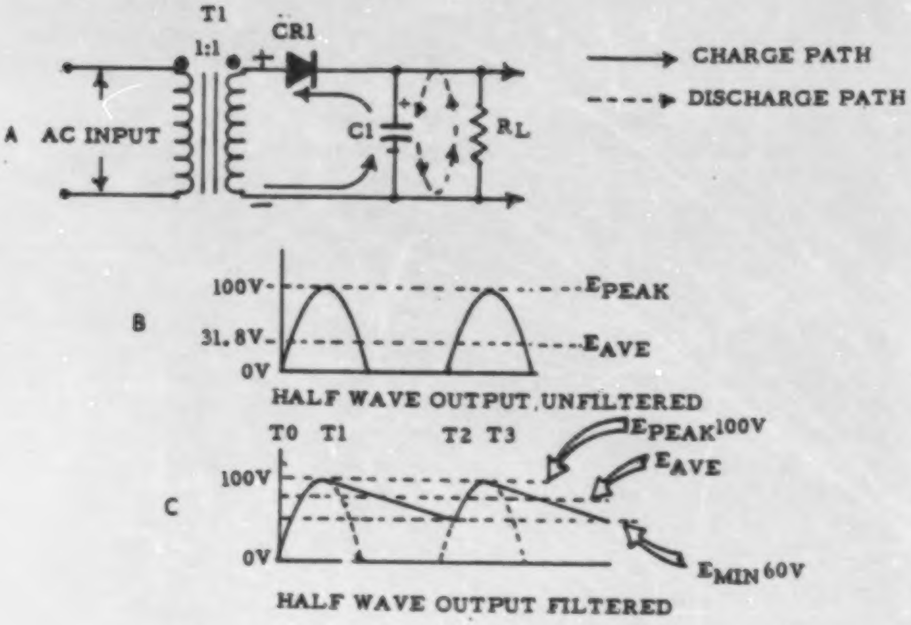

T1
1:1
CR1
+
−
CHARGE PATH
DISCHARGE PATH
A
AC INPUT
C1
RL
B
100V
31.8V
0V
EPEAK
EAVE
HALF WAVE OUTPUT, UNFILTERED
T0
T1
T2
T3
EPEAK 100V
EAVE
C
100V
0V
EMIN 60V
HALF WAVE OUTPUT FILTERED

Figure 2-2. Half Wave Rectifier With Capacitive Filter

and the value of R_L, the values of C1 and R_L will determine the ripple amplitude.

2-5. In figure 2-2B note that the ripple voltage of the unfiltered waveform is 100V peak-to-peak and the average voltage is 31.8 volts. With the addition of the filter capacitor, the output waveform in figure 2-2C shows that ripple amplitude decreases to 40 volts peak-to-peak and the average voltage increases to some level above 60 volts.

2-6. You will always find that the filter capacitor is placed in parallel with the load resistance. The smaller the discharge time constant, the larger the ripple amplitude, and the lower the average output voltage. Figure 2-3 shows the effect of changing the value of R_L and C on ripple amplitude and their effects on average output voltage. It can be seen in figure 2-3 that a large load (small R_L) placed on the rectifier with a capacitor filter will cause a decrease in average voltage and an increase ripple amplitude. In figure 2-3 a small value of filter capacitance will produce similar results.

2-7. SIMPLE INDUCTIVE FILTER

2-8. Another device that is used as a filter is the inductor. Both the inductor and capacitor are reactive devices which are capable of storing energy.

2-9. Figure 2-4 shows the inductive filter in a half-wave rectifier circuit. Note the inductor or "choke" is in series with the load resistance so that total current will

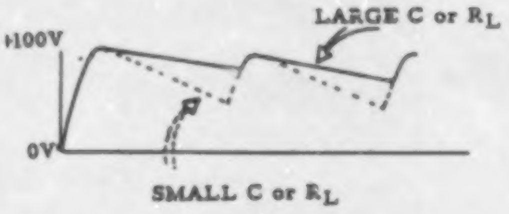


Figure 2-3. Effects of R_L and C on Output Voltage and Ripple Amplitude

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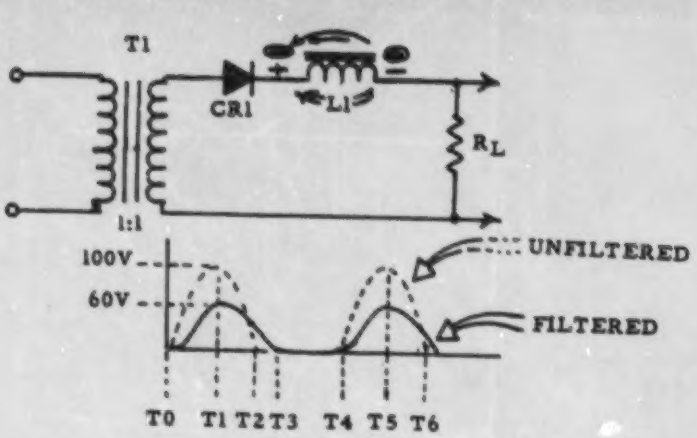

Figure 2-4. Half-Wave Rectifier With Inductive Filter

flow through it. Figures 2-3 and 2-4 show the unfiltered (dotted waveform) and filtered (solid waveform) output from the circuit.

2-10. This type of filter uses the reactive properties of an inductor. It will oppose a change in current and store energy in its magnetic field. The inductor, therefore, opposes any change in current and attempts to keep the load current and output voltage constant.

2-11. Refer to figure 2-4 for analysis of the inductive filter. From T0 to T1 (see the dotted waveform), the input voltage to an unfiltered rectifier will cause the current to increase rapidly to its peak value producing a peak voltage across the load resistance of 100 volts. From T1 to T2 the current and output voltage will decrease rapidly to zero. With the addition of a filter coil, L1, the current will rise slowly between T0 and T1 due to the inductive reactance of L1 opposing the increase in current. This will result in an electromagnetic field being built around L1 as indicated in figure 2-4. At T_1 the voltage applied to the anode of CR1 will begin to decrease, resulting in an attempted decrease in the current through L1. At this time the electromagnetic field will begin to collapse, the voltage polarity of L1 will reverse, (circled polarities on figure 2-4) and the negative voltage on the cathode from the collapsing fields will cause CR1 to continue to conduct. Note that CR1 continues to conduct for a short period of time after the completion of the positive alternation from T_1. At T_3 the magnetic field of L1 has completely collapsed, and diode CR1 ceases conduction. Note also that at time T_3 the output voltage is zero volt.

2-12. With an inductive filter, the ripple amplitude is smaller. The peak output voltage across R_L is less than the peak input voltage due to the voltage drop across L1. Compared to the capacitive filter under similar circuit conditions, the average output voltage from the inductive filter is less. The average output voltage from an inductive (choke) filter will remain more constant with large changes in load (current) than the capacitive filter. For this reason, it is used in circuits where there are large load (current) changes.

2-13. The output voltage from any power supply should remain constant in value. When a capacitor was used as a filter, it was found that if the load resistance changed, the average output voltage would change due to the change in ripple amplitude. Using the example of load resistance decreasing, it was found that ripple amplitude would increase. At the same time if load resistance decreased, load current would increase.

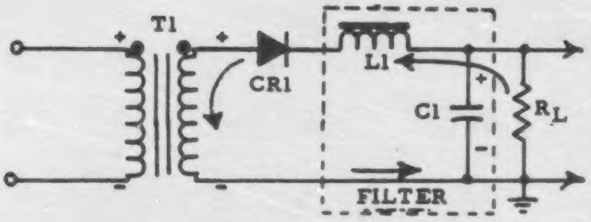

Figure 2-5. Half-Wave Rectifier with L-Type Inductor Input Filters

The inductor is used to oppose changes in current. As in our example, with an increase in current, the inductor would tend to oppose this increase in current and hold load current constant. The process of maintaining a constant value of current with a changing load resistance is called REGULATION. The inductor, when used as a filter, is placed in series with the LOAD resistance (refer to figure 2-4). As a result of placing the inductor in series with the load resistance, any change in load current will be detected by the inductor and the inductor will oppose the change in current. If current can be maintained or regulated to a constant value, then the average voltage will remain at a constant value, or will be regulated as well. If current and voltage are regulated, we can state that the power is also being regulated (P = EI). As we will see, some filters provide better regulation than others.

2-14. "L" TYPE FILTERS

2-15. "L" TYPE FILTERS are classified into two sub-groups: the "L-type inductive input" and the "L-type capacitive input" filters.

2-16. Figure 2-5 shows the half-wave rectifier with an L-type inductive input

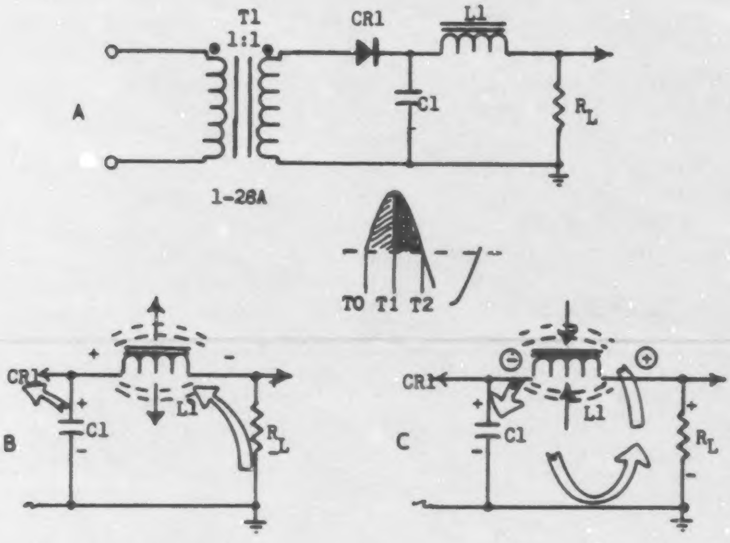

Figure 2-6. Capacitive Input L-Type Filter

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filter. The two components that comprise the filter are the inductor (L1) and the capacitor (C1). It is referred to as an "inductive input" filter because the inductor is connected to the rectifier output.

The diode (CR1) conducts during the positive alternation of the input sine wave. Current will flow from ground through R_L, L1, CR1, and through the secondary of T1. This will cause C1 to charge, and a magnetic field to build up around L1. The charge path for C1 now contains the reactance of L1. C1 will not charge to the peak voltage of the secondary due to the voltage drop across L1. As the positive alternation starts to decrease, C1 will start to discharge through R_L. The field around L1 begins to collapse and causes the polarity of voltage across L1 to reverse. The induced voltage, developed across L1, allows the diode (CR1) to continue to conduct for a longer period of time which will provide additional current to flow in the circuit. This additional current helps to maintain a smaller amplitude of ripple voltage. If the load resistance changes, there will be a change in current. Any change in current has to flow through L1 and the inductor will oppose these changes in current which will result in good current regulation. If current remains constant, the output voltage will remain constant and will result in good regulation. An inductive input filter provides for good regulation but a lower output voltage than that which could be obtained with the capacitive input L type filter.

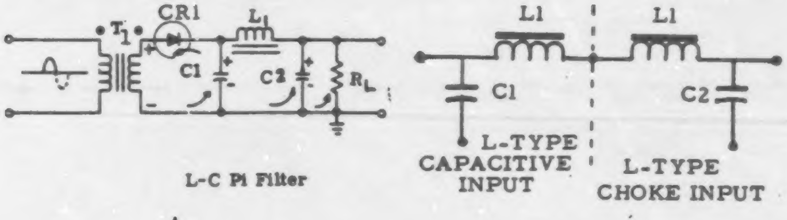
2-17. The second type of "L" type filter is the capacitive input "L" type filter. It has the characteristic of providing for a higher output voltage but poorer current and voltage regulation when compared to an inductive input "L" type filter. Figure 2-6A illustrates a half wave rectifier with a capacitive input "L" type filter. Figure 2-6B and 2-6C illustrate the current paths for charge (T0 to T1) and for discharge (T1 to T2).

During the positive alternation of the input voltage, CR1 will conduct and current will flow as shown in figure 2-6B. One path is through R_L and L1 and the other is the charging current of C1. Notice that C1 now charges only through the diode CR1 and will charge to the peak input voltage.

2-18. When the positive alternation of the input voltage starts to decrease, CR1 will cut off and C1 will begin to discharge through R_L and L1 (figure 2-6C). The magnetic field of L1 will also begin to collapse, providing a current through R_L which aids the capacitive discharge current. (Note the voltage polarities in figure 2-6C). Since C1 charged to the peak input voltage, the average output voltage will be higher than with an L-type inductive input filter. However, large load current changes on the capacitive input L-type filter would result in an increased ripple amplitude. An L-type inductive input filter gives a lower output voltage and good voltage regulation. A capacitive input L-type filter gives a higher output voltage, but the voltage regulation is poor. The L-type inductive input filter is used in applications which have large load current changes. Capacitive input filters are used in power supplies that have a relatively constant load or current drain.

2-19. PI-TYPE FILTERS

2-20. The Pi-type filter is a compromise between the two L-type filters just discussed. It will provide a relatively high output voltage



L-C Pi Filter

A.

B.

Figure 2-7. Half-Wave Rectifier with LC Pi-Type Filter

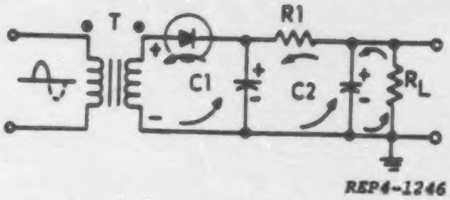


Figure 2-8. RC Pi-Type Filter.

with good voltage regulation. There are two Pi-type filters. One is the "L-C Pi-type" and the other is the "R-C Pi-type."

2-21. Figure 2-7A shows the LC Pi-type filter. The filter circuit is composed of L1, C1 and C2. It will display the properties of both the L-type filters just discussed. Figure 2-7B shows the equivalent circuit for an L-C Pi-type filter.

2-22. On the positive alternation of the input, CR1 will conduct, charging C1, C2, and L1. C1 charges to the peak and C2 to a somewhat lower voltage. When CR1 is cut off, both capacitors will discharge through R_L and the collapsing magnetic field about L1 will supply energy, aiding the discharge current of C1 and C2.

2-23. A somewhat less effective Pi-type filter is the R-C Pi-type filter shown in figure 2-8. In the RC Pi-type filters, the inductor is replaced with a resistor.

2-24. By replacing L1 with R1, a series voltage divider network is formed by R1 and R_L. This will result in a lower output voltage. Because R1 does not oppose current changes, it will not return energy to the load during the non-conducting time of CR1. The result will be decreased current regulation. For varying load or current changes, this type of a filter is not as good as that of the LC Pi-type filter.

2-25. Deleted.

2-26. Deleted.

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2-28. VOLTAGE DOUBLER

2-29. A voltage doubler is a circuit which converts AC to DC, provides filtering, and produces an output voltage which is approximately two times the peak voltage of the transformer secondary. A voltage doubler circuit is shown in figure 2-9.

2-30. The circuit is actually two half-wave rectifiers with capacitive filters. CR1, T1, and C1 make up one of the half-wave rectifiers. The other half wave rectifier is CR2, T1 and C2. The circuit is designed so the voltages across C1 and C2 will be series aiding and will result in an output voltage across R_L which is two times the peak voltage of T1 secondary. Figure 2-10A shows the current flow during the positive alternation of the input and the resultant voltage across C1. Note that C1 charges through the small

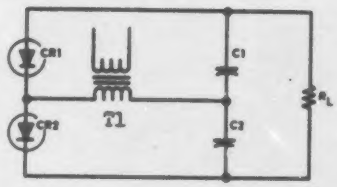
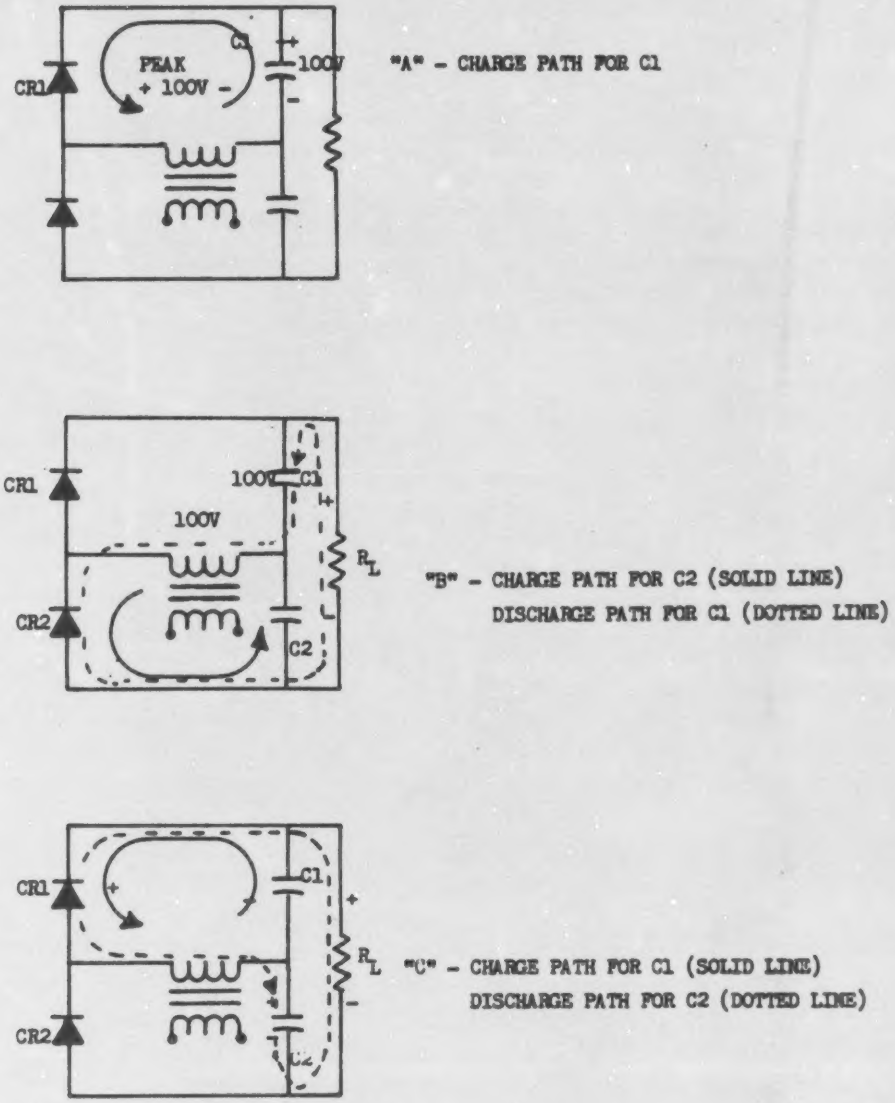


Figure 2-9. Voltage Doubler



"A" - CHARGE PATH FOR C1

"B" - CHARGE PATH FOR C2 (SOLID LINE)
DISCHARGE PATH FOR C1 (DOTTED LINE)

"C" - CHARGE PATH FOR C1 (SOLID LINE)
DISCHARGE PATH FOR C2 (DOTTED LINE)

Figure 2-10. Voltage Doubler Charge and Discharge Paths

resistance of CR1 and therefore, will charge very rapidly to the peak voltage of T1 secondary (100V peak).

2-31. During the negative alternation (figure 2-10B), C2 will charge to the T1 secondary peak voltage. CR1 is reverse biased and C1 will discharge. Note in figure 2-10B that C1 discharges through T1 secondary, CR2, and R_L. The voltage across C1 is series aiding with the secondary voltage of T1. R_L will feel the sum of the two voltages or 200V peak. C1 has a high resistance (R_L) in its discharge path and will discharge very slowly maintaining the voltage output at approximately 200V during this alternation.

2-32. When the polarity of the input reverses as in figure 2-10C, the capacitor C1 will recharge very rapidly and C2 will start its discharge through R_L, T1 and CR1. The voltages of C2 and T1 secondary are now series aiding across R_L. The output voltage across R_L is maintained at approximately 200V peak. Since an output pulse is produced for each alternation of the input sine-wave, the circuit is a full-wave rectifier with a ripple frequency twice the input frequency.

2-33. The high output voltage from the voltage doubler is possible due to the fact that the charges of capacitors C1 and C2 are added in the output. To maintain this high voltage output, the load resistance and capacitance must be large to produce a long discharge time. The load current drain on a voltage doubler must be small.

Chapter 3

VOLTAGE REGULATION

3-1. The output voltage developed by a source of power changes: (1) with a change in input and (2) when current is drawn from the source. Many electronic circuits operate satisfactorily with a moderate amount of variation in the supply voltage. Some circuits are very critical and even a slight deviation from the normal supply voltage will cause unsatisfactory operation. These circuits require the use of a voltage-regulating device. Crystal diodes manufactured for this purpose are called zener diodes. Sometimes referred to as avalanche diode or breakdown diodes, these diodes use the breakdown voltage and the avalanche current region of the PN junction. This chapter discusses zener diodes and electronic voltage regulators.

3-2. ZENER DIODE

3-3. "Zener" is a name given to a family of diodes designed to operate with reverse breakdown voltage. Zener diodes operate in the avalanche region of their characteristic curves, without damage.

3-4. The voltage current characteristics of a typical zener diode are shown in figure 3-1. With forward bias, the zener diode operates the same as a regular PN junction. With a small reverse bias across the PN junction the barrier potential is increased. This action causes a space charge depletion region or junction. Only a small leakage current will flow due to minority carriers.

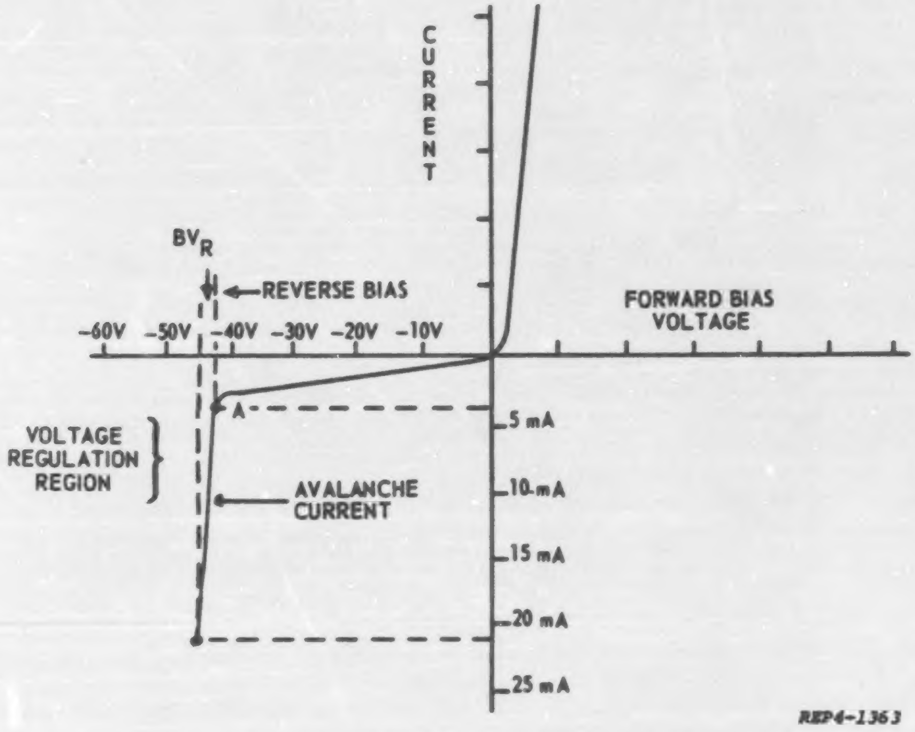


Figure 3-1. Zener Diode Characteristic Curve

3-5. Increasing the reverse voltage increases the velocity of the minority carriers. Some of these carriers collide with covalent bond electrons releasing them as carriers. This action has a cumulative effect called "avalanche ionization." It comprises a rapid increase in reverse current that, unless checked by a series limiting resistor, may destroy the semiconductor. The reverse voltage at which avalanche effect occurs is called the reverse breakdown voltage and is abbreviated BV_R.

3-6. The zener diode voltage regulator is operated between point A (Figure 3-1) and point B. At point A, the current is about 3 mA and the voltage across the zener is about 43 volts. At point B, the current is about 22 mA and the voltage across the zener is about 45 volts. Between points A and B, the current changes 19 mA as the voltage changes 2 volts.

3-7. A zener voltage regulator circuit is shown in figure 3-2, along with the schematic symbol of zener diode CR1. The zener diode is placed in parallel with the load and in series with the current limiting resistor R1. The voltage delivered to the load is controlled by the BV_R value of CR1. If the supply voltage (input from filter) decreases, the reverse voltage across CR1 will decrease. Therefore, the speed of the carriers in the crystal will decrease and reverse current will decrease. The current through R1 decreases with a proportionate decrease in voltage drop across R1. The decreased drop across R1 cancels some of the original drop in the supply voltage and keeps the voltage across the load fairly constant.

3-8. Zener diodes are designed to operate at various voltages. When a regulated voltage in excess of the rating of one zener diode is required, two or more diodes may be connected in series. Several regulated voltages can be obtained from a single rectifier power supply.

3-9. To illustrate the operation of a zener diode, we must use both figures 3-1 and 3-2. Figure 3-1 indicates that the current midway between points A and B is about 12 mA and the voltage across the zener is about 44 volts. Thus, the voltage across the load is also 44 volts. Current thru R1, therefore, is the sum of the load current and the zener current or 62 mA. The voltage drop across the 500-ohm R1 is 31 volts. The input voltage from the filter network is the sum of E_{R1} and E_{CR1} or 75 volts.

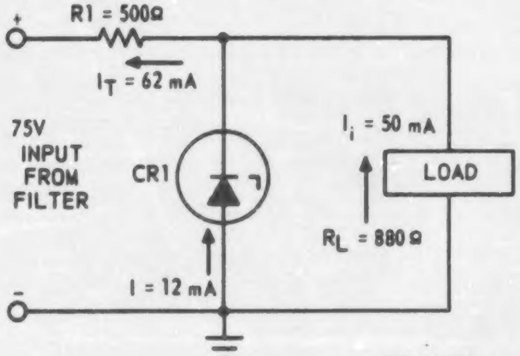


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Figure 3-2. Zener Voltage Regulator Circuit

3-10. If the voltage from the filter were to decrease to 69 volts, the voltage across the zener and the load would change to 43 volts. Figure 3-1 shows that with 43 volts across CR1, current through CR1 is 3 mA. The decrease of 1 mA through the 880-ohm load decreases E_{R1} by 5 volts. So, for a change in input voltage (from the filter) of 6 volts (75V to 69V), the load voltage changed only 1 volt (44V to 43V). Checking: $E_{R1} + E_{load}$ = 69V (26V + 43V) = 69V.

3-11. If the voltage from the filter were to increase to 81.5 volts, the voltage across the load would go to 45 volts. The increase of 10 milliamperes through CR1 (22 mA at 45V, figure 3-1) and the 1 mA increase through the load, increases the voltage drop across R1 to 36.5 volts (36.5V + 45V = 81.5V). The result is as follows: The voltage from the filter could have a change in amplitude of 12.5 volts (69V to 81.5V), but the voltage across the load would only change 2 volts (43V to 45V).

3-12. Even though a zener diode does regulate voltage, it has certain limitations. The current

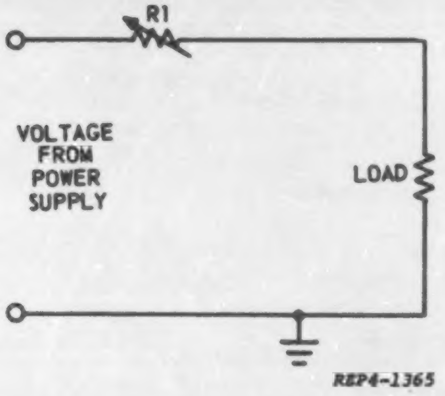

Figure 3-3. Equivalent EVR Circuit

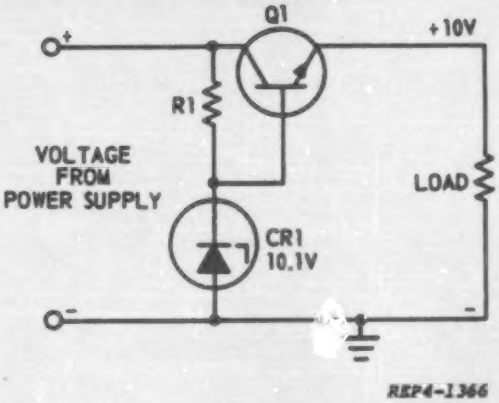

Figure 3-4. Simplified EVR Circuit

range (maximum to minimum) is limited; there is a voltage change between the minimum current and maximum current conditions; and the amplitude of the regulated voltage is fixed by the type of zener used. Electronic voltage regulators use amplifier circuits along with the zener diode to overcome the limitations of the zener diode alone.

3-13. ELECTRONIC VOLTAGE REGULATOR (EVR)

3-14. An electronic voltage regulator is a circuit designed to maintain the output voltage nearly constant regardless of input voltage or load changes. An electronic voltage regulator can be equated to the series resistive circuit, shown in figure 3-3. The load resistance is connected in series with variable resistor R1 across the output terminals of the power supply. The voltage from the power supply has ripple and is not regulated. Further, if the resistance changes, the voltage across the load cannot remain constant.

3-15. In figure 3-3, if R1 is increased as the input voltage goes up, the voltage across the load can be made to remain constant. An increase in E applied to a series circuit increases I total. A corresponding increase in R total will decrease I total to its original value. Further, if the size of R1 is decreased as the input voltage decreases, the output voltage remains constant. Likewise, if the load resistance is decreased, and R1 is decreased a proportional amount, the load voltage remains constant. This is the basic principle of an electronic voltage regulator circuit.

3-16. A simplified electronic voltage regulator circuit is shown in figure 3-4. A transistor has been inserted in place of a variable resistor. Recall that a transistor is a variable resistance and that its resistance can be controlled by electronic means. Zener diode regulator CR1 with current limiting resistor R1 develops forward bias for Q1. The zener is rated at 10.1 volts and, during normal operation, holds the voltage on the base of Q1 constant at this value. With Q1 conducting, a voltage of approximately 10 volts is developed across the load resistance. Therefore, the bias on Q1 during normal operation is the difference between the base and emitter voltages or .1 volt. With the base voltage of Q1 held constant by CR1, the only way the bias of Q1 can be changed is for the voltage on the emitter to change. Thus, the voltage on the emitter, which is also the load voltage, determines the resistance of Q1.

3-17. If, for any reason, the load voltage decreases, the bias on Q1 increases. With an increase in forward bias, the resistance of Q1 decreases and more current flows, bringing the load voltage back toward its original value.

3-18. Or, if the load voltage increases, the bias on Q1 decreases. A decrease in

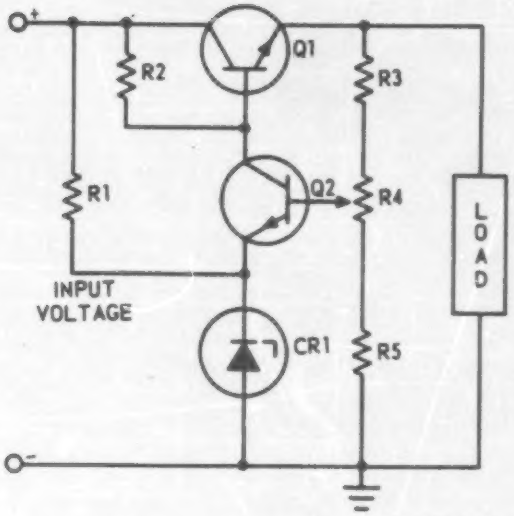

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Figure 3-5. EVR

forward bias of Q1 causes the resistance of Q1 to increase. This causes less current to flow, and the voltage across the load returns to the regulated value. The circuit is designed so that the resistance change in Q1 is proportional to a change in load voltage. This operation holds the voltage across the load relatively constant in case either the input voltage or the load resistance changes.

3-19. Although this is an improvement over the simple zener diode regulator, the simplified electronic voltage regulator still has limitations. Figure 3-5 shows a schematic diagram of a complete electronic voltage regulator circuit. Two class A amplifiers, Q1 in series and Q2 in shunt, detect and compensate for variations in source voltage or load. With the addition of Q2 and voltage divider network R3, R4, and R5, this circuit regulates the voltage across the load to a more constant value.

3-20. Transistor Q1 is in series with the load. The action of Q1 changing its resistance to hold the output voltage constant is still present. Notice that the base current of Q1 is now controlled by Q2. R2 is the collector load resistor for Q2 and the forward bias resistor of Q1. Resistor R1 is the current limiting resistor for CR1.

3-21. The bias for transistor Q2 is determined by the voltages on its emitter and base. The zener diode sets the emitter voltage, which is called the Q2 reference voltage. The voltage on the base of Q2 is developed by the voltage divider network (R3, R4, and R5) connected across the load. This arrangement continuously samples the output voltage. In other words, if the output voltage were to increase, the voltage on the movable arm of R4 will increase. So, with the emitter voltage of Q2 being held constant at all times, the conduction of Q2 is controlled by the voltage at the arm of R4.

3-22. To illustrate the operation of the electronic voltage regulator, let's discuss: (1) an increase of input voltage and (2) an increase in the load on the circuit. An increase in input voltage is felt across voltage divider R3, R4, and R5. The voltage at the arm of R4 will go in a positive direction. This increase in voltage at the base of Q2 increases its forward bias. Transistor Q2 conducts harder and increases the voltage drop across R2. This makes the voltage on the base of Q1 less positive. A less positive voltage on the base of Q1 decreases the forward bias of Q1, which increases its resistance. With resistance of Q1 increased, more voltage is dropped across Q1 (collector-to-emitter). The increase in voltage drop across Q1 nearly equals the increase in input voltage (from the filter) and the load voltage remains relatively constant. This action is instantaneous, and the EVR circuit maintains a regulated output voltage anytime the input voltage increases. A decrease in input voltage results in just the opposite action within the circuit, and the output voltage remains at the regulated value.

3-23. An increase in load on the circuit means that the resistance of the load has decreased. When this occurs, load voltage decreases. Any change in load voltage is felt across voltage divider R3, R4, and R5. A decrease in load voltage causes the voltage at the arm of R4 to decrease. The decrease in voltage at the base of Q2 reduces its forward bias. Transistor Q2 then conducts less, and the current through its load resistor decreases. This causes the voltage on the base of Q1 to increase (becomes more positive). The increase in voltage on the base of Q1 increases forward bias and causes the resistance of Q1 to decrease. The decrease in resistance of Q1 (emitter-to-collector) causes the voltage across Q1 to decrease, leaving more voltage across the load. The decrease in voltage across Q1 nearly equals the decrease in load voltage and, for all practical purposes, the load voltage remains constant.

3-24. Transistor Q1 is referred to as the "series regulator." The voltage on the arm of R4 is called the "error signal," and Q2 is the "differential" or "error" amplifier since it amplifies the error signal. The zener diode provides the reference voltage for error amplifier Q2. This regulator circuit provides very close regulation of the output voltage.

3-25. Another characteristic of the electronic voltage regulator circuit is the fact that the output voltage can be adjusted to a specific value. Resistor R4 is the output voltage adjust. If the arm of R4 is moved up, the forward bias on Q2 increases, and Q2 conducts harder. The voltage across R2 increases and the voltage on the base of Q1 decreases. The forward bias of Q1 is thus decreased, so the resistance of Q1 increases. This action will reduce the output voltage.

3-26. If the arm of R4 is moved down, the forward bias of Q2 decreases; Q2 conducts less, and the voltage on the base of Q1 increases, which decreases the resistance of Q1. This action will cause the output voltage to increase to a higher value.

4-1. TROUBLESHOOTING THE HALF WAVE RECTIFIER

4-2. In order to troubleshoot the power supply, you must be familiar with the function of its component parts. For our explanation, we will discuss the effects of open or shorted diodes and capacitors. The function of the diode, as you recall, was to change AC to pulsating DC. The filter capacitor was used to change pulsating DC to DC. In performing this task, the ripple amplitude is decreased and the average output voltage increases. Keeping these functions in mind, let's look at the half wave rectifier with a capacitive filter shown in Figure 4-1.

4-3. The total current which flows in the power supply in Figure 4-1 must flow through CR1. An open diode would cause all current flow through R_L to cease, C1 would no longer charge, and the output voltage would drop to zero volts.

4-4. Figure 4-2 shows the equivalent circuit when CR1 shorts. Without the diode to rectify the AC, we have an AC voltage applied to C1. The reactance of C1 to the AC is very low ($X_C = \frac{.159}{fc} = 26$ ohms). This would cause a large current flow in the primary and secondary circuits of T1, causing the fuse F1 to open, removing the applied voltage. Output voltage, in turn, would become zero. This problem illustrates the importance of having a properly fused power supply. A circuit that is fused with too large a fuse or not fused at all, would have a very large load under this condition and would probably cause serious damage to the transformer and other circuit components.

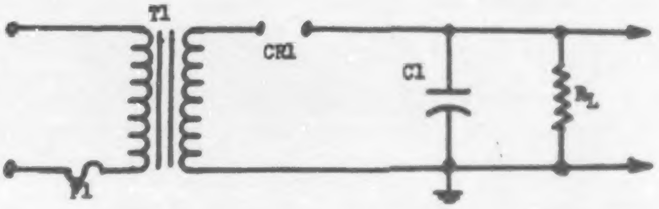


Figure 4-1. Half-Wave Rectifier With Capacitive Filter (CR1 Open)

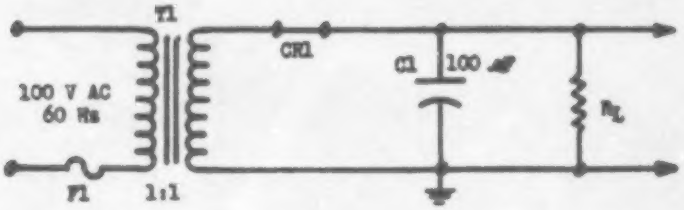

T1
CR1
C1
100 µF
100 V AC
60 Hz
RL
F1
1:1

Figure 4-2. Shorted Diode In a Half-Wave Rectifier (Shorted CR1)

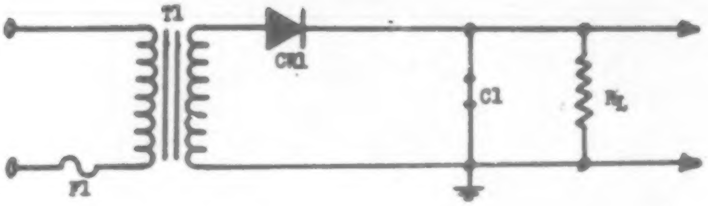

T1
CR1
C1
RL
F1

Figure 4-3. Shorted Capacitor In a Half-Wave Rectifier

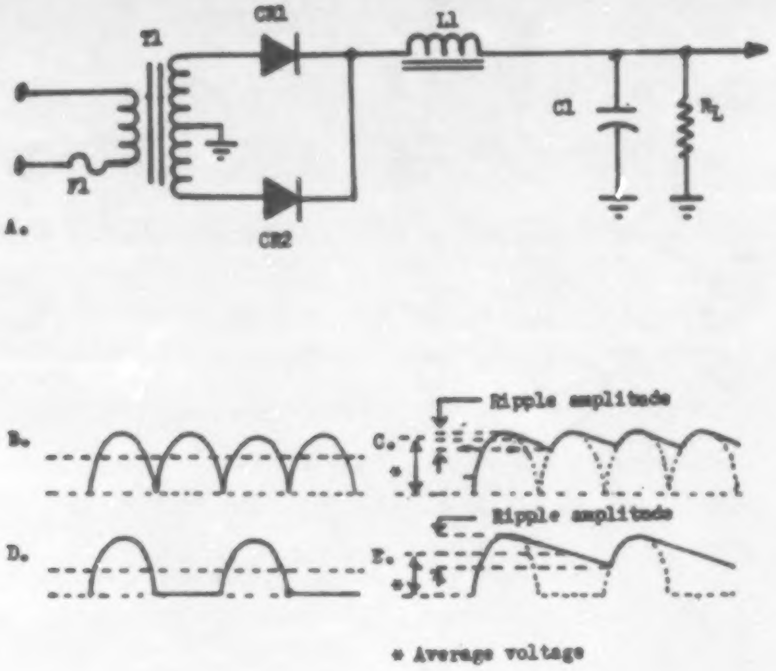


Figure 4-4. Full-Wave Rectifier with L-Type Inductive Input Filter (Open CR1 or CR2)

4-5. SHORTED CAPACITOR

4-6. Figure 4-3 shows the equivalent circuit formed when the filter capacitor shorts.

4-7. When the filter capacitor C1 shorts, notice it shorts the load resistance which limits the current in the rectifier circuit. CR1 is the only resistance in the secondary circuit of T1 and when it is forward biased, its resistance is very low. As a result, there would be a large current flow in both primary and secondary circuits of T1 probably destroying the fuse F1. This again would point out the necessity of having a properly fused power supply. This circuit is designed so fuse F1 will blow before the maximum current limitation of the diode is reached. The output voltage would drop to zero under these conditions.

4-8. OPEN CAPACITOR

4-9. If the filter capacitor, C1, in Figure 4-2 opens, we would have no filtering action. The rectifier output would then show a high ripple amplitude and average output voltage would decrease.

4-10. TROUBLESHOOTING THE FULL-WAVE RECTIFIER

4-11. Figure 4-4A shows the full-wave rectifier with an L-type inductive input filter.

4-12. Figure 4-4B illustrates the normal unfiltered output and Figure 4-4C the filtered output showing ripple frequency, ripple amplitude, and average output voltage. Opening either diode results in the circuit becoming a half-wave rectifier with the resultant wave-

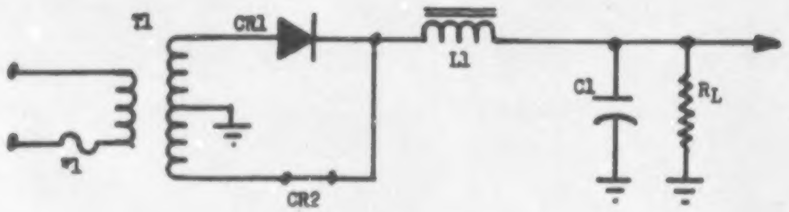


Figure 4-5. Full-Wave Rectifier With Shorted Diode

forms shown in Figures 4-4D and E. Note ripple frequency has decreased, ripple amplitude increases and average output voltage decreases.

4-13. OPEN FILTER CAPACITOR

4-14. If the filter capacitor opens, the output waveform would approach that shown in Figure 4-4B (unfiltered). L1 would still do some filtering, however it is very ineffective without C1. As a result, the ripple amplitude increases and the average output voltage decreases. Compare the two waveforms of Figures 4-4B and 4-4C (filtered and unfiltered).

4-15. SHORTED DIODE (CR1 OR CR2)

4-16. Figure 4-5 shows the equivalent circuit if one of the diodes (CR2) becomes shorted.

4-17 With CR2 shorted, CR1 is placed directly across the secondary winding of

TROUBLE	OUTPUT VOLTAGE	RIPPLE AMPLITUDE	RIPPLE FREQUENCY
CR OPEN	NO CURRENT NO OUTPUT	NONE	NONE
CR SHORT	EXCESSIVE CURRENT NO OUTPUT BLOWN FUSE	NONE	NONE
C OPEN	LOWER THAN NORMAL NO FILTERING	GREATER THAN NORMAL	NO CHANGE
C SHORT	EXCESSIVE CURRENT NO OUTPUT BLOWN FUSE	NONE	NONE

A. Half Wave

TROUBLE	OUTPUT VOLTAGE	RIPPLE AMPLITUDE	RIPPLE FREQUENCY
DIODE OPEN	LOWER THAN NORMAL HALF-WAVE RECTIFICATION	GREATER THAN NORMAL	DECREASE BY 1/2
DIODE SHORT	EXCESSIVE CURRENT NO OUTPUT BLOWN FUSE	NONE	NONE
C OPEN	LOWER THAN NORMAL FILTERING DECREASE	GREATER THAN NORMAL	NO CHANGE
C SHORT	EXCESSIVE CURRENT NO OUTPUT BLOWN FUSE	NONE	NONE

B Full Wave

Figure 4-6. Troubleshooting Summary Table

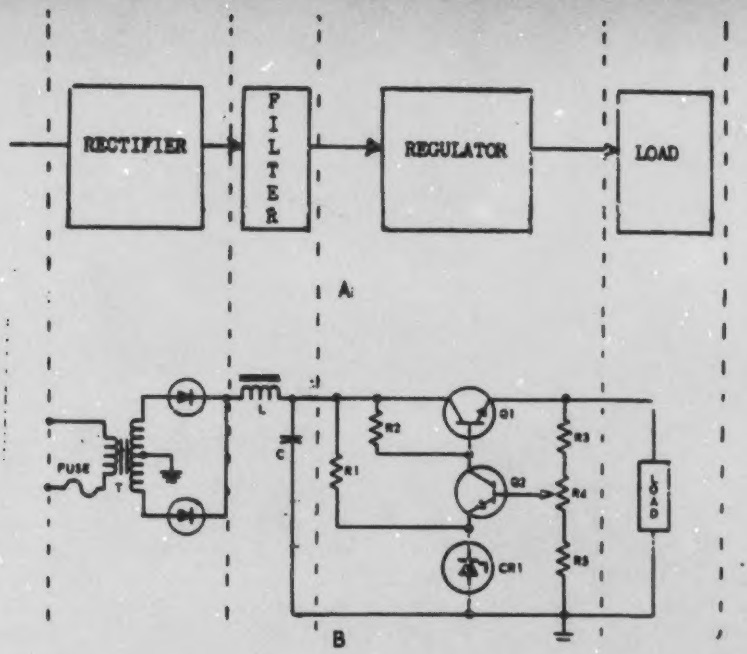


Figure 4-7. Rectifier, Filter, and Regulator

transformer T1. When it is forward biased its very low resistance would place a very large load on both primary and secondary windings. The excessive current through fuse F1 will cause it to burn out. This condition would result if either CR1 or CR2 shorts.

4-18. SHORTED FILTER CAPACITOR

4-19. Shorting the filter capacitor C1 would short out the load resistance in parallel with it. Excessive current would flow, destroying fuse F1.

4-20. The tables in Figure 4-6 provide a summary of the effects of open or shorted capacitors and diodes in the half-wave and full-wave rectifiers. Note that a shorted diode or capacitor results in an excessive load which destroys the fuse. An open diode or capacitor results in a lower output voltage and higher ripple with the exception of the half-wave whose output goes to zero with an open diode.

4-21. TROUBLESHOOTING THE ELECTRONIC VOLTAGE REGULATOR (EVR).

4-22. Thus far, we have taken a look at some of the problems that could result with open and shorted components in either the rectifier or the filter circuit of the Power Supply. The voltage regulator plays an important role within the Power Supply in that it will, under normal operating conditions, regulate the voltage under varying load conditions.

4-23. Before we begin to talk about troubles that could exist in the voltage regulator, let's review some of the points that have been made about an Electronic Voltage Regulator and how it relates to the other circuits in our power supply. By referring to the block diagram, Figure 4-7A, you can see that the voltage regulator fits between the FILTER and the LOAD, the load being the many circuits that the power supply is providing power for. It should be apparent that any malfunction occuring in the REGULATOR will cause a change in the amount of voltage that is being provided to the LOAD. The circuit diagram shown in Figure 4-7B illustrates how the circuits would appear when connected together and are drawn to relate to the block diagram.

4-24. From your previous lessons that dealt with the Electronic Voltage Regulator, you will recall that the purpose of R4 was to provide a means of adjusting the output voltage to the correct value that is required by the LOAD. Refer to Figure 4-7B, recall that we found that by moving the wiper arm of R4 toward R3 that the output voltage would decrease and that by moving the wiper arm of R4 toward R5 that the output voltage would increase. These points serve as a basis for understanding the circuit which we are going to troubleshoot. It would be well to review why these statements are true.

4-25. Moving the wiper arm of R4 toward R3 in Figure 4-7B will cause an increase in the amount of voltage seen at the base of Q2. An increase in voltage at the base of Q2 will cause Q2 to conduct harder and its collector voltage will decrease. A decrease in the collector voltage of Q2 is directly coupled to the base of Q1 and is seen by Q1 as a decrease in forward bias. This decrease in forward bias at Q1 will cause Q1 to conduct less and the resistance represented by Q1 will increase. Remember that Q1 is in series with the load and that by changing the amount of bias at the base of Q1, it will affect the amount of resistance exhibited by Q1 and in turn the amount of voltage drop across it. Following the sequence outlined above, test your understanding of the circuit by moving the wiper arm of R4 toward R5. You should be able to prove to yourself that the output voltage increased due to an increase in forward bias at the base of Q1 decreasing its resistance.

4-26. As an electronic technician, one of the first checks that you will make in the system that you are going to maintain is to determine whether or not the Power Supply is providing the correct value of voltage. In our first problem, we are going to assume that you have made this check with a voltmeter and have found that the VOLTAGE MEASURED AT THE OUTPUT IS HIGHER THAN NORMAL AND THAT ADJUSTING R4 DOES NOT CHANGE THE OUTPUT VOLTAGE indicating that the REGULATOR is not functioning properly.

4-27. The faulty component in this case could be an open resistor such as R3. If R3 is open, the voltage seen at the base of Q2 would be zero. With zero volts at the base of Q2, it would not conduct and the collector voltage would be more positive than normal resulting in an increase in forward bias for Q1. With Q1 conducting harder than normal, its resistance would be low. The lower resistance of Q1 results in a decreased voltage drop across it and the voltage being provided to the load would be higher than normal. The REGULATOR would not be able to regulate for changes in voltage with R3 open because transistor Q2 would be unable to detect changes in output voltage.

4-28. Other components in the circuit that could cause the same type of symptoms are listed below:

CR1 Open - With CR1 open, Q2 is prevented from conducting and its collector voltage would be more positive. Q1 would detect this as an increase in forward bias resulting in a decrease in voltage drop across Q1 and in turn a rise in output voltage.

Q2 Open - With Q2 open, we would have a more positive voltage applied to the base of Q1 resulting in an increase in forward bias for Q1.

Q1 shorted - With Q1 shorted, the entire voltage would be seen at the load as a high and unregulated value of voltage.

4-29. In our discussion of troubleshooting thus far, we have talked about the symptom of the output voltage being higher than normal. Suppose that in our check of the power supply that we find that the output voltage is LOWER THAN NORMAL.

4-30. One of the components in the REGULATOR that could cause this type of a symptom would be a shorted zener diode such as CR1. Under normal conditions, CR1 provided a positive regulated voltage for the emitter of Q2 in order that Q2 would be able to detect any voltage changes appearing at the base of Q2. With CR1 shorted, the emitter of Q2 would be at ground potential resulting in an increase in forward bias at the base of Q2. Q2 would conduct harder than normal. The collector voltage of Q2 would decrease in value and this decrease would be coupled to the base of Q1 as a decrease in forward bias for Q1. Decreasing the forward bias of Q1 would be seen as an increase in the resistance of Q1 and in turn more voltage would be dropped across Q1. With more voltage dropped across Q1, less voltage would be seen at the load with the resultant symptom of output voltage LOWER THAN NORMAL.

4-31. Other components in the Electronic Voltage Regulator that could cause similar symptoms are listed below:

R3 Shorted - With R3 shorted, there would be an increase in forward bias seen at the base of Q2 resulting in a decrease in collector voltage. This decrease in collector voltage would be detected as a decrease in the forward bias for Q1 resulting in an increase in resistance of Q1. More voltage would be dropped across Q1 and less voltage would be seen at the load.

R-2 Open - With R2 open, there is no longer a path for forward bias for Q1. Q1 will not conduct and the output voltage will be zero.

Q1 Open - If Q1 is open, the DC path for current flow is open and in turn the output voltage will be zero.

4-32. The question that should now arise is "How do you know which one of the components is causing the malfunction if there are a number of components that will provide the same symptoms?" The answer to this question lies in your ability to use the PSM6 and your ability to interpret the readings that you take. As an example, if we use the symptom of OUTPUT VOLTAGE IS LOW and use the voltmeter to determine which component is faulty, a voltage measurement of zero volts at the emitter of Q2 would tell us that CR1 was not providing the positive voltage that it is supposed to provide. With R2 or Q1 open, our output voltage would not only be low, it would be zero. With R3 shorted, a check at the emitter of Q2 would provide a positive voltage measurement that is being developed by CR1. A further check at the base of Q2, with R4 at its upper extreme, would show that the base voltage of Q2 is the same as the output voltage.

Chapter 5

POWER AMPLIFIERS

5-1. Usually amplifier systems have a series of amplifiers connected together. A small signal is applied to a first or "input" amplifier, and its "output" becomes the input to the next circuit in the series. The purpose of each amplifier circuit is to receive the signal, increase its strength, and pass it on to the next amplifier. Whether the system contains few or many amplifiers, the function of each stage is to increase the signal level. In the last stage, the signal has sufficient power to perform some useful work.

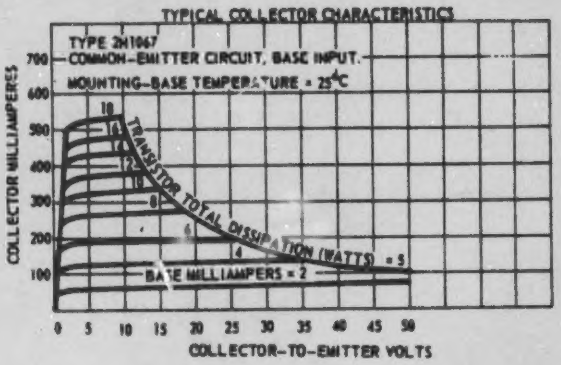
5-2. In general, the last stage of a series of amplifiers is called the power amplifier. The power stage differs from the preceding stages in that it is designed to obtain maximum power rather than maximum voltage gain.

5-3. One transistor limitation is the amount of power that it can dissipate. The maximum power dissipation (PDMAX) rating of a transistor is the maximum allowable power; to exceed this rating would destroy the transistor.

5-4. Maximum COLLECTOR dissipation is the maximum power that may be safely dissipated by the collector. This operating limit is represented on characteristic curves as a constant power dissipation curve, maximum power dissipation curve, PDMAX, or total dissipation. PDMAX is the product of the DC quantities of V_{CE} and I_C.

5-5. If the manufacturer lists the maximum power dissipation of a transistor as 2 watts, the product of collector voltage times collector current must not exceed 2 watts. Under AC conditions the instantaneous values of voltage or current may exceed this value as long as the average power does not.

5-6. Figure 5-1 is a characteristic curve chart for a 2N1067 silicon transistor. Notice that the lines terminate on the transistor total dissipation curve, which is 5 watts.



MIP4-666

Figure 5-1. Power Dissipation Curve for 2N1067 Transistor PD_{MAX}

Dividing 5 watts by 500 ma results in:

$$\frac{PD_{MAX}}{I_C} = \frac{5}{.5} = 10 \text{ volts}$$

Locate this point at the intersection of the 500-mA I_C and 10-volt V_{CE} lines. Another point is 250 mA and 20 volts; a third point is 100 mA and 50 volts. Note that the product of each set of values is 5 watts. Connecting all the points with a line produces the power dissipation curve. This curve shows the maximum collector current for any value of collector-to-emitter voltage. The maximum power dissipation curve is used to establish the operating (Q) point and the load line. The load line and operating point must always be to the left of the maximum power dissipation curve. The load line may fall tangent to curve, but it must never fall to the right of the power curve.

5-7. Since a power amplifier is operated at high power levels, the heat generated internally in the transistor becomes a major concern. The stability of a transistor decreases as junction temperature increases.

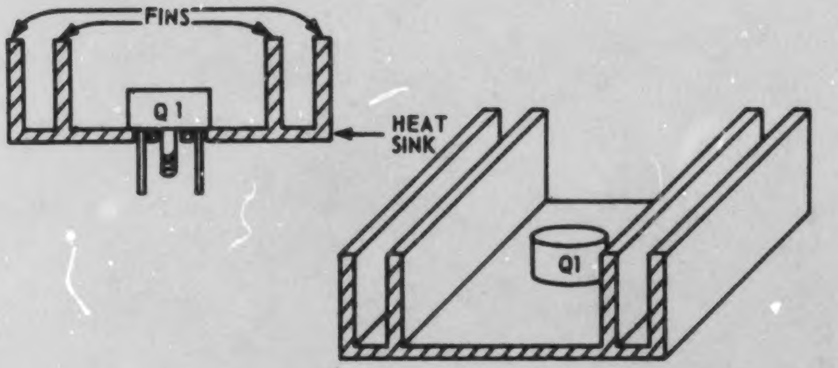


Figure 5-2. Heat Sink

A device called a "heat sink" is used to move the heat away from the transistor junctions. The heat sink shown in figure 5-2 consists of metal with a very large surface area, attached directly to the metal case of the transistor. Some cases have fins to dissipate heat into the surrounding air more rapidly. The heat produced at the junction of the transistor transfers to the metal case of the transistor. Since the heat sink makes direct contact with the metal case, the heat transfers to the heat sink, and then the air. This lowers the operating temperature at the junction of the transistor.

5-8. In many cases the schematic diagram of a high-power amplifier is the same as for a low-power or medium-power amplifier. The major difference is in the power rating, physical construction, use of heat sinks, and mounting methods.

5-9. Another difference (aside from the fact that the power amplifier is the last stage) is that the power amplifier is designed for maximum output power rather than maximum gain. The power amplifier stage has a smaller value of load impedance than the preceding stages. To have maximum transfer of power from a source to a load, the load impedance must equal the source impedance. The same applies to the power amplifier. This is called "impedance matching." Since power is a function of current squared times resistance ($P = I^2R$), R is kept as small as possible to allow maximum current flow.

5-10. Double-Ended (Push-Pull) Power Amplifier

5-11. A circuit arrangement that is commonly used as the final or power amplifier stage is the double-ended or "push-pull" amplifier. A push-pull circuit contains two amplifiers which operate in 180° phase relationship. This produces additive output components of the desired wave, with cancellation of certain unwanted products. A push-pull amplifier consists essentially of two transistors connected as shown in figure 5-3.

5-12. Two transformers, T1 and T2, use a center-tapped winding. Resistor R1 provides the forward-bias voltage for Q1 and Q2 and establishes the operating point for both transistors. One half of the primary of transformer T2 represents the collector load impedance for Q1 and the other half represents the load impedance for Q2. T2 also provides impedance matching between the high output impedances of the transistors and the low impedance of the speaker voice coil.

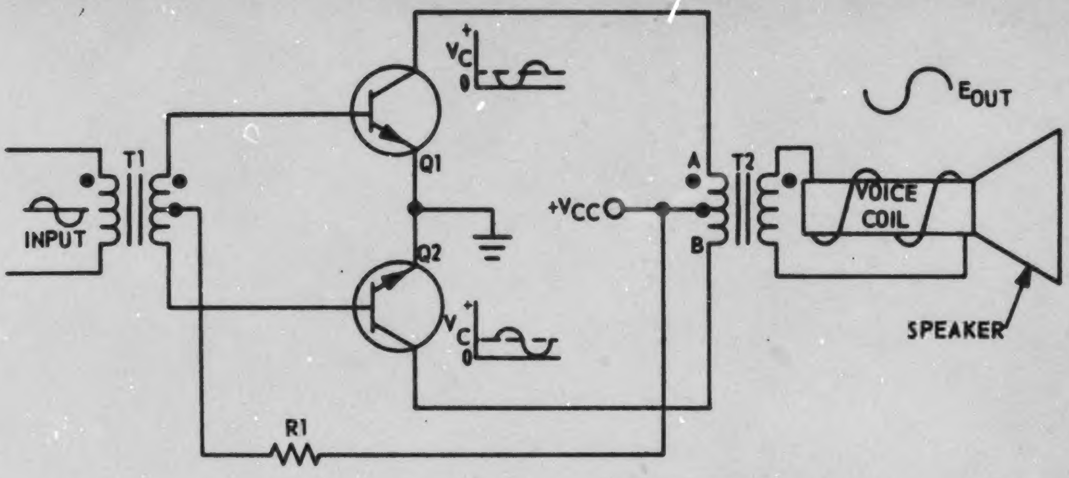


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Figure 5-3. Class A Push Pull Power Amplifier

5-13. With no signal input, Q1 and Q2 conduct equally through both parts of the center-tapped primary winding of T2 to V_{CC}. The voltage at point A equals the voltage at point B; both are less positive than the center tap, and no voltage is induced in the T2 secondary winding.

5-14. Assume Class A operation. Through the use of center-tapped transformer T1, two signals, 180 degrees out of phase and equal in amplitude, are applied as inputs to the push-pull amplifiers.

5-15. On the positive alternation of the input signal the potential on the base of Q1 will go in a positive direction. The potential on the base of Q2 will go in a negative direction. Since both transistors are NPN type, the potentials applied to their base elements cause the conduction of Q1 to increase and Q2 to decrease. The increase in Q1 collector current causes point A to become less positive because of the increased voltage drop across the top half of T2. The collector voltage waveform shown at Q1 is a graph of the potential at point A.

5-16. The decrease in conduction of Q2 causes the potential at point B to increase (become more positive). Thus, the potential at point B is increasing positive while the potential at point A is decreasing positive. This causes a potential difference to be developed across the entire primary of T2 and appears as the negative alternation of the output waveform.

5-17. On the negative alternation of the input signal the reverse of the above action occurs. The conduction of Q1 decreases and the conduction of Q2 increases. the collector voltage waveforms go more positive at Q1 and less positive at Q2. The polarity of the voltage developed across the primary of T2 is reversed from the previous alternation.

5-18. The power output from this class A push-pull circuit can be more than twice that obtainable from a single-ended, class A, power amplifier. An added advantage of this circuit is cancellation of all even harmonics, (provided the transformer circuits are balanced). Any noise or variations from the V_{CC} source affect both circuits. Since the primary of T2 is center-tapped, equal voltage changes at A and B cancel in push-pull operation.

5-19. The class A push-pull power amplifier is used where minimum distortion is the primary consideration and efficiency is deemed less important. A disadvantage of class A operation is low efficiency.

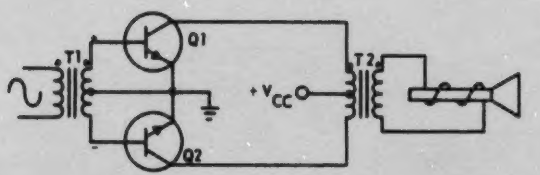


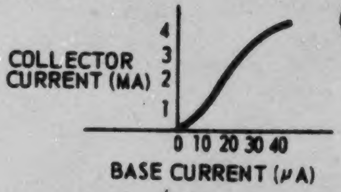
Figure 5-4. Class B Push-Pull Amplifier

5-20. Figure 5-4 shows a simplified schematic diagram of a transformer-coupled, Class B, push-pull amplifier. This circuit can be identified by the fact that there is no forward bias network for the base-emitter junction. With no input signal both transistors are cutoff. Each transistor conducts when a positive polarity is felt on its base, on alternate half cycles of the input signal. A positive potential at the top of the T1 secondary causes Q1 to conduct but the negative potential, at the bottom of T1 secondary, holds Q2 cutoff. The next alternation reverses the polarities so that Q1 is cut off and Q2 conducts. The output signals combine in output transformer T2.

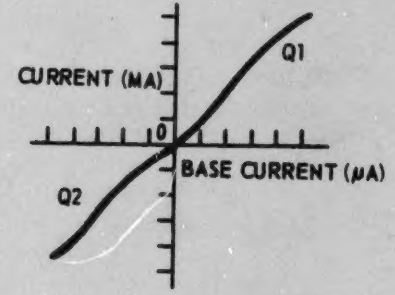
5-21. Greater efficiency is obtained with Class B push-pull because neither transistor conducts with no-input-signal, and no power is wasted.

5-22. An indication of the output current waveform for a given signal current input can be obtained by considering the dynamic transfer characteristics for the amplifier. Assume that the two transistors have identical dynamic transfer characteristics. The characteristics for one of the transistors is shown in figure 5-5A. The variation in output (collector) current is plotted against input (base) current under load conditions. Since two transistors are used, the overall dynamic transfer characteristic for the push-pull amplifier is obtained by placing the two curves back-to-back (figure 5-5B).

5-23. Note that the zero lines of each curve are lined up vertically to reflect the zero bias current. In figure 5-6, points on the input base current sine wave are projected onto the dynamic transfer characteristic curve. The corresponding points are determined and projected as indicated to form the output collector current waveform. Note that severe distortion occurs at the "cross-over" points, where the signal passes through zero. This is called crossover distortion. This type of distortion becomes more severe with low signal input currents. Crossover distortion can be reduced, or eliminated, by using a small forward bias on both transistors of the push-pull amplifier (Class AB operation).



A. ONE TRANSISTOR



B. TWO TRANSISTORS

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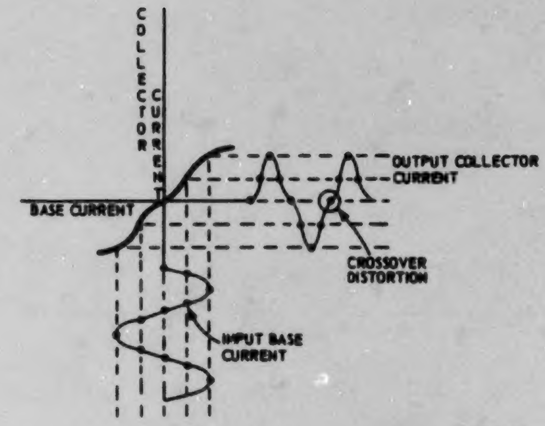
Figure 5-5. Transistor Curves for Push-Pull Class B


COLLECTOR CURRENT
BASE CURRENT
OUTPUT COLLECTOR CURRENT
CROSSOVER DISTORTION
INPUT BASE CURRENT

REP4-671

Figure 5-6. Class B Push-Pull Wave Forms (Crossover Distortion)

5-24. A class AB push-pull amplifier is shown in figure 5-7. Resistor R1 provides the forward bias which establishes the operating point just above cut off. This small forward bias eliminates crossover distortion.

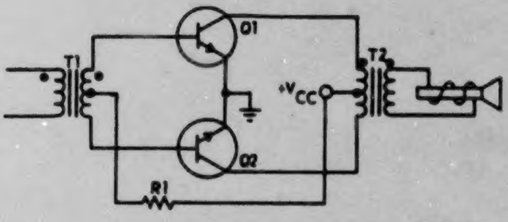

T1
Q1
Q2
T2
+VCC
R1

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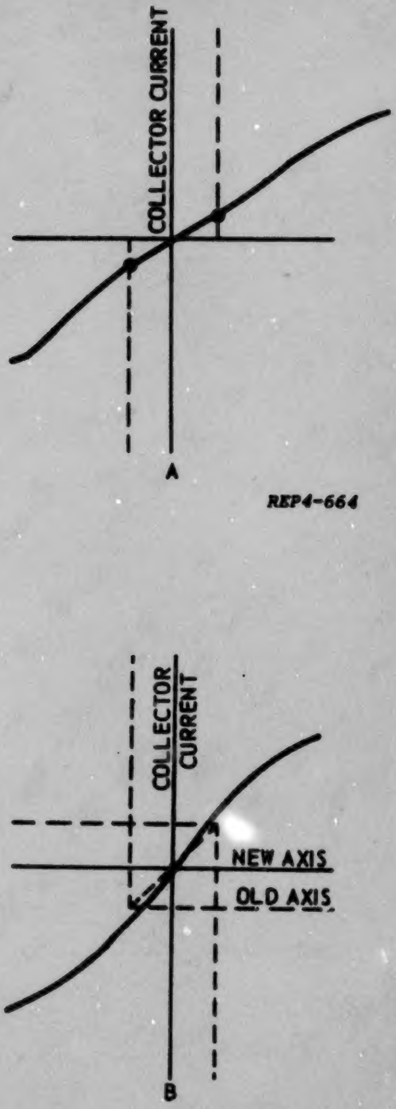
Figure 5-7. Class AB Push-Pull Power Amplifier


COLLECTOR CURRENT
A
COLLECTOR CURRENT
NEW AXIS
OLD AXIS
B

REP4-664

REP4-663

Figure 5-8. Class AB Push-Pull Transfer Curves

5-25. A study of the dynamic transfer characteristic curve of the amplifier demonstrates the reduction or elimination of crossover distortion. In figure 5-8A, the dynamic transfer characteristic curve of each transistor is placed back-to-back. The two curves are back-to-back and not combined. The dashed lines indicate the base current values when forward bias is applied. With forward bias applied, the curve of each transistor

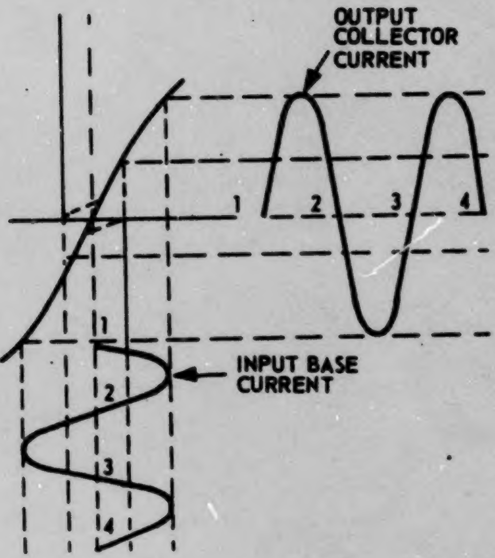


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Figure 5-9. Class AB Push-Pull Waveforms

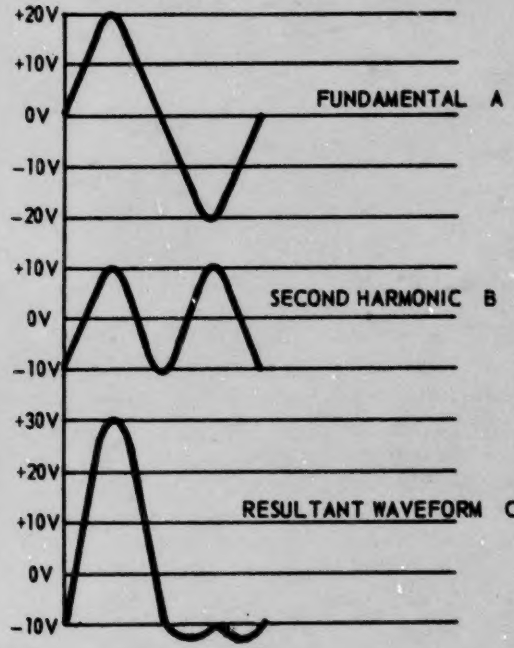

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Figure 5-10. Harmonics in Single-ended Amplifiers

must be aligned at the base current line (dashed line). Figure 5-8B shows the result of moving the charts so that the base current value of each transistor is aligned. Notice that the resulting dynamic transfer curve is practically straight through the crossover area.

5-26. In figure 5-9, points on the input base current (sine wave) are projected onto the dynamic transfer characteristic curve. The corresponding points are determined and projected as indicated to form the output collector current waveform. Compare this output current waveform with that shown in figure 5-6. Note that crossover distortion of Class B operation does not occur when a small forward bias (class AB operation) is applied.

5-27. Push-pull amplifiers provide cancellation of even harmonics if the circuit is balanced. This is illustrated in figure 5-11. Recall that a non-linear device causes distortion and generates harmonic frequencies. With a Class A push-pull amplifier, there should be no harmonic frequencies generated because the circuit operates on the linear portion of the transfer curve. However, class B or class AB operation will create harmonics and cause distortion. Figure 5-10c shows the output signal of a single-ended amplifier operated class AB. Note that one alternation

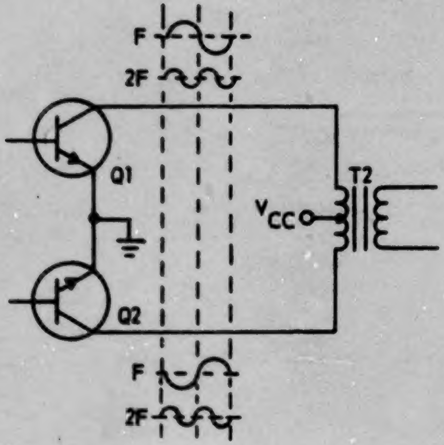

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Figure 5-11. Even Harmonic Cancellation

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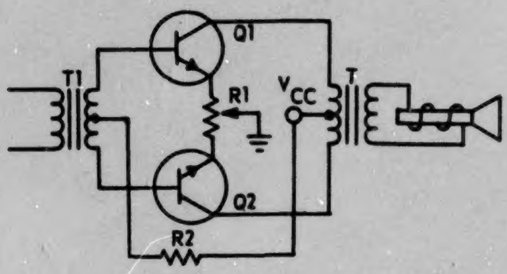

Figure 5-12. Balancing A Push-Pull Amplifier

(positive) is larger than the other (negative). By adding the fundamental frequency (figure 5-10A) to the second harmonic (figure 5-10B) the resultant waveform is shown in figure 5-10c. This is the same as the output of the class AB amplifier.

5-28. Figure 5-11 shows a push-pull amplifier and the relationship of the fundamental and second harmonic frequencies. The fundamental frequency (F) on the collector of Q1 is used as a reference; the fundamental frequency on the collector of Q2 is out of phase by 180 degrees. The second harmonic of F at Q1 is shown in-phase with F at the zero points; that is, as F goes through zero, the second harmonic goes through zero also. The second harmonic frequency of F at Q2 has the same phase relationship because Q2 and its circuitry are exactly the same as Q1. The harmonic frequencies (2F) appear at both ends of the output transformer (T2). With the top of T2 positive (first alternation of 2F at Q1) and the bottom of T2 positive at the same time (first alternation of 2F at Q2), there is no difference of potential across the transformer primary. Therefore, the second harmonic frequency does not develop an output signal. In other words, the second harmonic frequency cancels. All even harmonic frequencies will experience this same cancellation effect. Odd harmonics, however, will not cancel.

5-29. Since components cannot be made with identical characteristics (i.e., exact resistance), a variable resistor in the emitter circuit is used to balance a push-pull amplifier circuit. Refer to R1 in figure 5-12. For example, if Q1 has slightly more resistance than Q2, then resistor R1 can be adjusted to compensate for the small difference.

5-30. Phase Splitters

5-31. "Driver Stage" is a term used to describe the amplifier which is used to supply the "driving" or input signal to the final, or power amplifier, stage. The push-pull power amplifier input requires two signals equal in amplitude and opposite in phase. A driver stage that supplies two equal amplitude output signals, differing in phase by 180 degrees from a single input is called a "phase splitter" or "phase inverter."

5-32. In the push-pull amplifier we just studied, center-tapped transformer T1 provides two signals of equal amplitude, 180 degrees out of phase, to two transistors Q1 and Q2. Although the transformer is a simple means of developing the required signal for a push-pull amplifier, economy, size, and weight may prohibit its use.

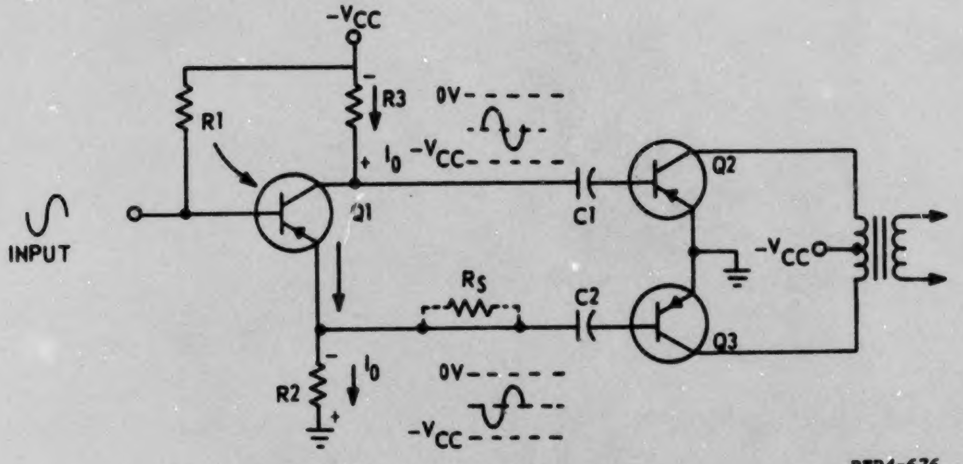

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Figure 5-13. One-Stage Phase Splitter

5-33. Figure 5-13 shows a "split-load" phase inverter. Also called a "paraphase amplifier," or "phase splitter," this circuit develops two signals, 180 degrees out of phase, without the use of a transformer. Resistor R1 establishes the base current. When the input signal aids the forward bias (base becomes more negative, PNP transistor), the output current I_C increases. The increased output current causes the collector of Q1 to be less negative (positive direction) with respect to ground. The emitter of Q1 becomes more negative with respect to ground. When the input signal opposes the forward bias, the output current decreases, the collector goes negative, and the emitter less negative (Positive direction).

5-34. This action produces two output signals that are 180 degrees out of phase with each other. They will be equal in amplitude if R2 equals R3.

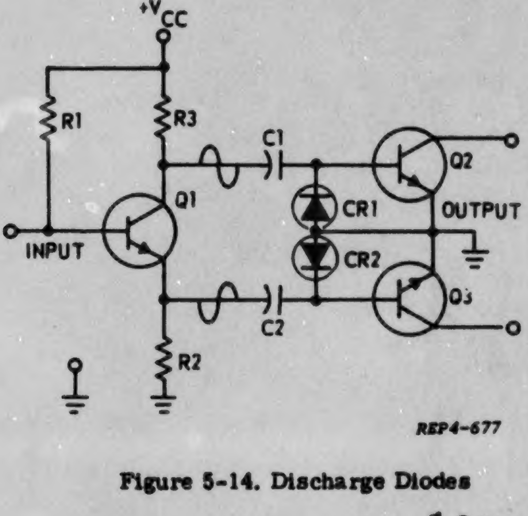

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Figure 5-14. Discharge Diodes

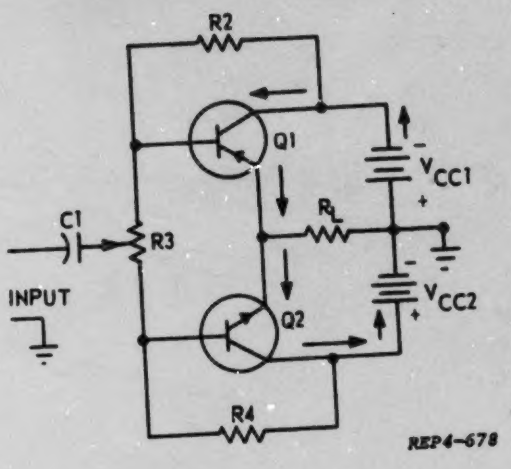

Figure 5-15. Complementary-Symmetry Circuit

5-35. However, when resistor R2 equals resistor R3, an unbalanced output impedance results. The collector output impedance of transistor Q1 is higher than its emitter output impedance. This disadvantage is overcome by inserting series resistor Rs between C2 and the top of R2. The values of R2 are chosen so that the output impedances of the collector and emitter are balanced. This eliminates distortion of strong signal currents. The signal voltage lost across the series resistor is compensated by making R2 higher in value than R3.

5-36. Notice that emitter resistor R2 is unbypassed in order to develop one of the output signals. This unbypassed emitter resistor reduces the voltage gain to less than one. The frequency response of the phase-splitter amplifier circuit is wide when compared to a center-tapped transformer.

5-37. DISCHARGE DIODE

5-38. A class B push-pull amplifier that uses capacitive coupling in the input circuit has limitations. Refer to figure 5-14 as we discuss the need for discharge diodes.

5-39. Transistors Q2 and Q3 are the push-pull amplifiers and Q1 is the phase splitter. Q2 and Q3 are operated with zero bias. Assume a positive signal alternation on the collector of Q1. This causes C1 to charge through the low resistance of the forward-biased base-emitter junction of Q2.

5-40. When the negative alternation of the signal is present on the collector of Q1, C1 tries to discharge through the reverse-biased base-emitter junction. The high resistance on the reverse-biased junction forms a long time constant for discharge of C1. It cannot discharge more during the next positive alternation. The charge across C1 is in series with the input signal. This shifts the operating point of Q2 toward cutoff. The same action occurs with Q3.

5-41. To equalize the charge and discharge time of the coupling capacitors, discharge diodes CR1 and CR2 are connected across the base-emitter junctions. This prevents the signal from shifting the operating points of Q2 and Q3.

5-42. Complementary-Symmetry

5-43. Junction transistors are available as matched PNP and NPN types. The direction of electron flow in the terminal leads of the one type of transistor is opposite to that of the other type.

5-44. When the transistors are connected in a single stage, the DC electron path in the output circuit is completed through the collector-emitter junctions in series. This is referred to as a complementary-symmetry circuit (figure 5-15). The circuit provides the advantages of conventional push-pull amplifiers without the need for a phase-inverter stage, or a center-tapped transformer.

5-45. Figure 5-15 shows PNP transistor Q1 and NPN transistor Q2 in a complementary-symmetry connection. A negative-going signal forward biases transistor Q1 and causes it to conduct. A positive-going input signal forward biases transistor Q2 and causes conduction. As one transistor conducts, the other is cutoff because the signal that forward biases one, reverse biases the other.

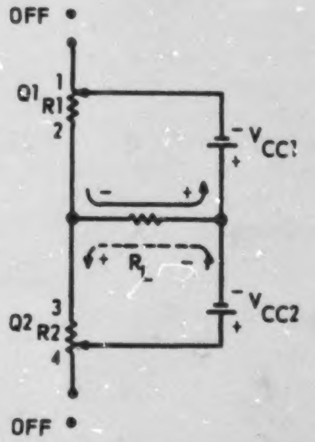

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Figure 5-16. Simplified Output Circuit of Complementary-Symmetry Amplifier

5-46. The resultant action in the output circuit can be understood by considering the circuit of figure 5-16. This is a simplified version of the output circuit. The internal emitter-collector circuit of Q1 is represented by variable resistor R1, and of Q2 by variable resistor R2. With no input signal and class B operation (zero base current), the arms of the variable resistors are positioned to maximum resistance. No current flows through the load resistor R_L. As the incoming signal goes positive, Q2 conducts and Q1 remains cutoff. Variable resistor R1 remains in the maximum resistance position. The variable arm of resistor R2 moves toward point 3. Current passes through the series circuit consisting of V_{CC2}, resistor R_l and, variable resistor R2 (Q2). The amount of current flow depends upon the magnitude of the incoming signal. The current flows in the direction of the dashed arrow, producing a voltage with the indicated polarity. When the input signal goes negative, Q1 conducts and Q2 cuts off. Current flows in the direction of the solid arrow, from V_{CC1} through variable resistor R1 and load resistor R_L. This produces a voltage across resistor R_L with the polarity indicated. Notice the current through R_L changes directions.

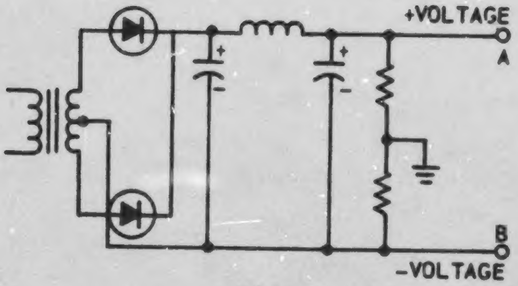

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Figure 5-17. Power Supply for a Complementary-Symmetry Amplifier

5-47. For class A operation of this circuit a voltage divider network, connected from $-V_{CC1}$ to $+V_{CC2}$, is used to apply forward bias. Collector current is not cut off at any time. In the simplified circuit (figure 5-16), variable resistors will not be in the maximum resistance position at any time. Current in the output circuit flows out of the negative terminal of battery V_{CC1} and V_{CC2} in series aiding, through resistors R1 and R2, and back to the positive terminal of battery. No resultant current flows through resistor R_L. Under these conditions, the output circuit can be considered a balanced bridge. The arms of the bridge consists of R1 and R2 and batteries V_{CC1} and V_{CC2}. When the input signal goes negative, the variable arm of R1 moves toward point 2 and R2 moves toward point 4. Again, the bridge is unbalanced and electrons flow through R_L in the direction of the solid-line arrow.

5-48. In either class A or B operation, no direct current flows through the load. The voice coil of a loudspeaker may be connected directly in place of R_L. Class AB operation is sometimes used to prevent the crossover distortion problem of class B operation.

5-49. Since two different transistors are used (one NPN and one PNP), two voltage polarities are required. A common method of obtaining different polarities from a single source is shown in figure 5-17. The output of the power supply uses a voltage divider arrangement with ground in the middle. This supplies a positive voltage at point A and a negative voltage at point B.

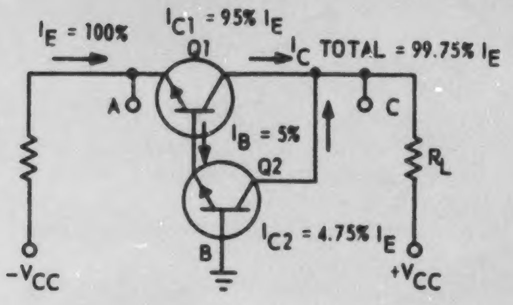

Figure 5-18. Compound-Connected Common Base

5-50. Compound Connected Amplifiers

5-51. The current, voltage, and power gains of a common base transistor amplifier are directly related to alpha, recall the forward current transfer ratio. This factor is the ratio of the output current (I_C) to the input current (I_E); the higher the alpha, the higher the current gain of a transistor. A compound-connected amplifier is a circuit designed to increase alpha.

5-52. Figure 5-18 shows a compound-connected transistor circuit. Note that the base of transistor Q1 is connected to the emitter of transistor Q2, and that the two collectors are connected in the common-base configuration. The following computations show that alpha (that is, the ratio of total collector current to input current) is greater than that of a single transistor.

5-53. For the circuit shown in figure 5-18, assume that alpha of each transistor is equal to .95. The input current to transistor Q1 is designated I_E. If only Q1 were used the output current (I_C) would be .95 times I_E.

5-54. However, the collector current of Q1 and Q2 add together in the compound-connected circuit. Collector current of Q1 (I_{C1}) is equal to .95 of I_E (input). The base current of Q1 (I_B) equals the emitter current less the collector current, or .05 of I_E. Since the base current of Q1 is the emitter input current of Q2, the collector current of Q2 is obtained by multiplying alpha (.95) times the emitter current of Q2 (.05). This gives a value of I_{C2} of .0475. The total current through R_L (output current) is equal to the sum of the collector currents of Q1 and Q2. So I_C1 plus I_{C2} equals .95 plus .0475 or .9975. This represents an alpha of .9975.

5-55. The two compound-connected transistors (figure 5-18) can be considered as a single unit having an emitter (point A), a collector (point C) and a base (point B). The ratio of output current (I_C) to input current I_E is .9975. This is the forward current transfer ratio for the compound connection, and it represents an increase from a single unit which has an alpha .95.

5-56. Compound-connected transistors in a circuit of any configuration can, therefore, be considered as a single unit with a high forward current transfer ratio.

5-57. Troubleshooting a Push-Pull Amplifier

5-58. Figure 5-19 shows a push-pull amplifier. R1 and R2 form a voltage divider to

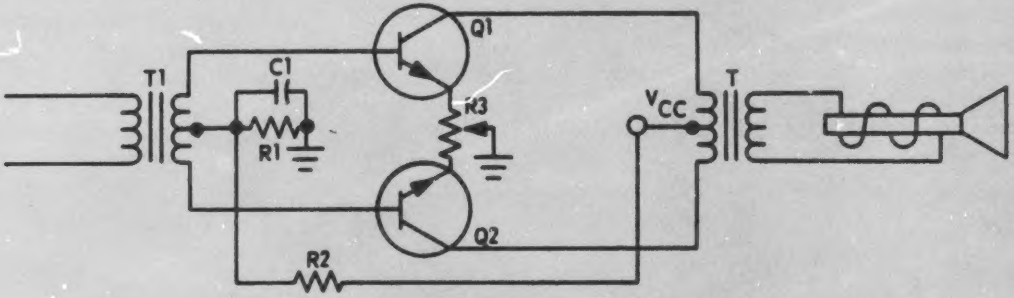

Figure 5-19. Push-Pull Amplifier

provide forward bias to the base of Q1 and Q2. C1 prevents degeneration of the input AC signal. If the primary of T1 were to open, there would be no input signal coupled to the base of either transistor. Since the DC current paths and bias network have not been affected, all DC voltages would be normal, but there will be no output signal. The same symptoms are present when the primary of T1 is shorted. If either the top or bottom half of the secondary of T1 is open, no signal will be coupled to the corresponding transistor. For example, assume the top of T1 secondary opens.

There will be no signal present on the base of Q1. Also, since the base current path for Q1 is broken, Q1 will be cut off. Q2 will still have approximately normal voltages and signals and will amplify. Since only one transistor can amplify, though, the output signal will be smaller than normal (weak) and may be distorted. The base voltage of Q1 will be zero, and collector voltage will be Vcc. Similar symptoms occur when the bottom of T1 secondary tap lead open, except Q2 is cutoff. Should the center tap lead open, forward bias for both Q1 and Q2 is removed which will cut Q1 and Q2 off, and no output signal will be produced.

5-59. If R1 is shorted, there will be no forward bias voltage except from the input signal. This results in class B operation and will produce crossover distortion in the output signal. With no input signal applied, both transistors will be cut off (V_C = Vcc). Should R1 open, the bias voltage will increase (less voltage drop across R2.) The DC collector voltage will be lower than normal, and the output may be distorted due to nonlinear operation (near saturation) of Q1 and Q2. Capacitor C_1 places the center-tap of T1 at AC ground, preventing any of the input signal from being lost across R1. If C1 opens, some of the input signal will be developed across R1, reducing the amount of signal felt across the base-emitter junctions of Q1 and Q2. Therefore, the output signal will be smaller than normal, but the DC voltages will remain normal. Shorting C1 will produce the same symptoms as a shorted R1. Should bias resistor R2 open, Q1 and Q2 would operate with zero bias voltage, resulting in class B operation. The symptoms will be the same as with R1 shorted. Shorting R2 will place Vcc on each base lead, and the excessive bias will either blow the fuse on the power supply, destroy the transistors, or both. If the wiper arm of R3 is open, the emitter current path for both transistors is broken. Therefore Q1 and Q2 are cut off and no output signal will be developed. Collector voltages will each be Vcc; base voltages will be slightly higher than normal. Shorting R3 will tie both emitters directly to ground. If the transistors are not closely matched, some distortion may occur in the output signal. With the center-tap of the primary to T2 open, there will be no collector voltage on either Q1 and Q2, and no output signal will be developed. If either half of T2's primary is open, there will be no collector voltage on the corresponding transistor. The output signal will be weak since only one transistor will amplify. If the secondary of T2 opens, the amplifiers will function normally, but no output signal will be developed in the secondary winding. There will be no output signal, and the signals present in the collector circuits may be weak and distorted due to the overload. This may also damage components in the amplifier.

Chapter 6

NARROW BAND AMPLIFIERS

6-1. Before entering into a detailed analysis of narrow band amplifiers, let's discuss the schematic diagram and general operation of typical RF amplifiers. Figure 6-1 illustrates the schematic diagram of a transistor RF amplifier.

6-2. The amplifier uses PNP transistor Q1 in the common emitter configuration. The primary of transformer T1 forms a parallel resonant (tank) circuit with C1. Observe that the tank circuit is between the antenna and ground. Only voltages at or near the tank's resonant frequency, however, will induce high current in the T1 primary winding. The selected frequency is called the "signal." The signal in the primary induces a voltage in the secondary of T1, which is applied to the base of transistor Q1. This causes Q1's collector current to vary in accordance with the applied signal. The amplified signal is developed across the collector tank circuit, made up of C4 and the T2 primary.

6-3. The DC operating point of Q1 is established by the voltage divider R1 and R2. Resistors R1 and R3 provide stabilization, and C3 prevents degeneration by placing the emitter at AC ground. C2 and C5 act as "decoupling" capacitors to isolate the RF signal from the power supply V_{CC}. R4 is a voltage dropping resistor, used to supply the proper collector voltage to Q1. The antenna and the collector tank circuits are tuned to resonate at the same frequency to improve selectivity. Selectivity is the ability of a circuit to select one frequency or band of frequencies and reject all others. The output of RF amplifier stage Q1 is transformer coupled through T2 to the next stage.

6-4. A single stage is seldom sufficient to provide the required RF amplification. Usually, two or more RF stages are connected in cascade, and the resultant bandwidth is narrower than that of a single stage.

6-5. The following discussion explains the reason for this effect. To simplify the explanation, let's assume that the amplifiers have an amplification factor of one. Figure 6-2 is a block diagram of two cascaded RF amplifiers. Notice that the two amplifiers require three tuned circuits, T1, T2, and T3. The capacitors of the tuned circuits are ganged (connected on a common shaft) to permit adjustment of the three circuits at the same time to the same resonant frequency.

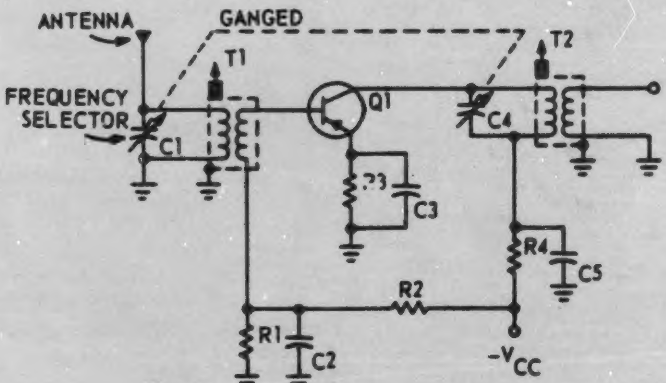

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Figure 6-1. Transistor RF Amplifier

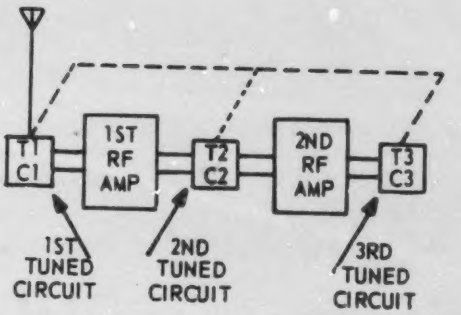

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Figure 6-2. Block Diagram of Cascaded RF Amplifiers

6-6. Suppose three frequencies of equal amplitude are applied to the antenna input. The RF amplifier is tuned to the center frequency, Fo. The other two frequencies, Fy and Fx, appear equidistant below and above the resonant frequency. See figure 6-3.

6-7. Figure 6-3 shows the response curves produced by cascading tuned circuits. Curve 1 represents the response of the first RF amplifier stage, including the first and second tuned circuit. Curve 3 is the response of the two RF amplifiers in cascade, including the three tuned circuits. The maximum voltage developed across the tuned circuits at the resonant frequency is taken as 100% for purpose of reference. The frequencies Fy and Fx coincide with the half-power points of the first tuned circuits (Curve 1).

6-8. If the maximum voltage developed across the first tuned circuit is 10 volts the voltage developed by Fy and Fx at the half-power points will be equal to .707 x 10 = 7.07 volts. The bandwidth of the first tuned circuit is shown as BW_1 in figure 6-3. The three frequencies (Fo, Fy, and Fx) feed through the first RF amplifier and are applied to the second tuned circuit. Recall the amplification factor is 1, so the signals pass through the amplifier with no amplification. Since the tuned circuits are identical, the resonant frequency Fo will be 10 volts out of the second tuned circuit; 100% x 10 volts = 1 x 10 = 10 volts.

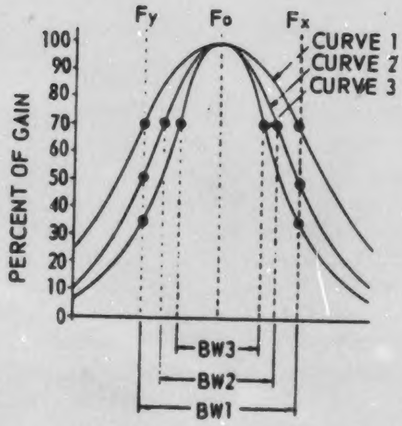

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Figure 6-3. Response Curves for Cascaded-Tuned Circuits

6-9. The voltage developed by Fy and Fx across the second tuned circuit at the half power points, will be .707 x 7.07 = 5 volts. Curve 2 (figure 6-3) for 1st and 2nd tuned circuits in cascade shows the gain at Fy and Fx to be down to 50% of maximum. The separation between the half-power points of Curve 2 is less than Curve 1.

6-10. BW_2 shows that the bandwidth for two tuned circuits is less than for a single tuned circuit.

6-11. A similar action occurs with the third tuned circuit. The amplitude of Fy and Fx across the third tuned circuit will be .707 x 5 = 3.54 volts. Curve 3 (figure 6-3) indicates that passing Fy and Fx through three tuned circuits has reduced their amplitudes until they are now only 35.4% of the maximum value. The 70.7% points of curve 3 have moved even closer to Fo making bandwidth BW_3 as shown. Notice that the bandwidth decreases with the addition of each stage containing a tuned circuit.

6-12. You can see that it is necessary to have the bandwidth of each individual circuit wider than the required overall bandwidth of the receiver. Figure 6-3 also indicates that adding stages containing tuned circuits

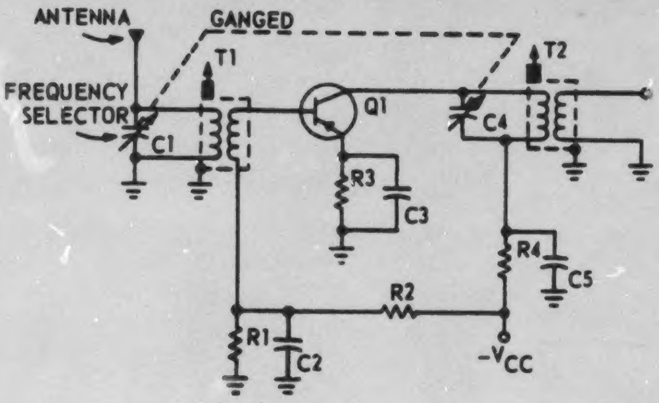

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Figure 6-4. Transistor RF Amplifier

increases the slope of the response curve, thereby increasing the selectivity of the receiver.

6-13. Noise voltages having the same frequencies as the desired signal will be amplified. Thus, the amplitude of the desired signal voltage induced in the antenna must be large in relation to the amplitude of any noise present with in the bandwidth. Noise voltage whose frequencies do not lie within the bandwidth (or bandpass) of the receiver can be ignored. Noise voltages can be minimized by decreasing the bandwidth. This results in an increased signal-to-noise ratio.

6-14. Trouble Shooting Solid State Narrow-Band Amplifier

6-15. Troubleshooting narrow band amplifiers is no different than troubleshooting the common audio amplifiers previously discussed. The important thing is to know the purpose of the components and how they are arranged in relation to the DC and AC sources. Use figure 6-4 for our discussion on troubleshooting.

6-16. Notice in figure 6-4 that many of the circuit components are inherent to all amplifier circuits and consequently their symptoms of malfunction will also be the same.

6-17. Since you have already studied troubleshooting techniques and symptoms of malfunction for the most common components found in audio circuits, such as DC bias resistors, emitter swamping resistor, collector load resistor and AC by-pass capacitors, we will limit our troubleshooting discussion to those components which are unique to the narrow band or RF amplifiers, the tuned circuits.

6-18. You recall that by cascading tuned amplifiers, the overall bandwidth would decrease, selectivity would increase, gain would increase and the signal-to-noise ratio would improve. These relationships were shown in figure 6-3 for a cascaded circuit containing 2 amplifiers and 3 tuned circuits.

6-19. To simplify the troubleshooting of narrow-band amplifiers we will use only 2 tuned tanks and 1 amplifier as shown in figure 6-4. The response curves for figure 6-4 would appear like those in figure 6-3.

6-20. As we discuss various component malfunctions in the narrow-band amplifier circuit (Figure 6-4), keep in mind the relationship of BW, selectivity, gain and signal-to-noise ratio.

6-21. Malfunction: C1 open.
Symptoms: Output signal amplitude lower

than normal; bandwidth increased; signal-to-noise ratio decreased (more noise); bias voltage normal; collector voltage (Vc) normal; resonant frequency (fo) of 1st tank circuit higher than normal. Reason for symptoms: With one tuned circuit malfunctioning, total "Q" decreases, selectivity decreases; consequently, above symptoms will occur. Capacitance of the 1st tank circuit has decreased, therefore the resonant frequency (fo) increases.

6-22. Malfunction: Primary T1 open.
Symptom: No output signal; bias voltage normal, collector voltage (Vc) normal.
Reason for symptoms: Input signal is not coupled across T1. Opening primary of T1 does not affect normal direct current (DC) path for Q1.

6-23. Malfunction: C_4 Open.
Symptoms: Output signal amplitude lower than normal (gain decreased); bandwidth increased; signal to noise ratio decreased (more noise); resonance frequency of output tank circuit is higher than normal.
Reason for symptoms: Total circuit "Q" is decreased which causes symptoms above.

6-24. Malfunction: Primary of T2 open
Symptoms: No output signal; collector voltage (Vc) of "Q1" is zero; Q1 will not amplify.
Reason for symptoms: DC path through collector is open; therefore, amplifier goes dead and no signal can be developed across open collector tank circuit.

6-25. Malfunction: C1 or Primary of T1 shorted.
Symptoms: No output signal, bias and collector voltage normal.
Reason for symptoms: All incoming signals shorted out; DC path through Q1 is not affected so bias and collector voltage should be normal.

6-26. Malfunction: C4 or Primary of T2 shorted.
Symptoms: No output signal at secondary of T2; slight increase in DC voltage in the collector circuit.
Reason for symptoms: Output coupling is shorted out; slight increase in Ic caused by the elimination of the small DC resistance of the primary winding of T2.

6-27. Malfunction. Secondary of T1 shorted.
Symptoms: No output signal; forward bias of Q1 increases slightly; Vc decreases slightly.
Reason for symptoms: By shorting secondary of T1, no signal can be coupled to Q1 for amplification. With a short across the small DC resistance of the secondary windings, the forward bias current would increase slightly, hence Vc would decrease.

6-28. Malfunction: Secondary of T2 shorted.
Symptoms: No output signal; bias and collector voltages normal.
Reason for symptoms: Output signal shorted out; normal DC functions in base and collector of Q1 isolated by transformer and, for all practical purposes, they would not be affected.

6-29. We have seen some of the theoretical symptoms that would occur for certain malfunctions within the narrow-band amplifier circuit, particularly the tank components. The components not covered in this troubleshooting section, but which were a part of the circuit in figure 6-4, are normally common to all amplifiers. Refer to previous troubleshooting on audio amplifiers for a review of the common components and their symptoms of malfunction.

6-30. In summary, narrow band amplifiers use resonant circuits which establish the selectivity and sensitivity of the system. Coupling circuits include resonant tanks which provide a high Q and impedance matching characteristics.

6-31. Transformers

6-32. The characteristics and physical construction of transformers used as coupling devices at high frequencies are quite different from those used in audio frequencies. The primary or the secondary (and in some cases both) windings of RF transformers are tank circuits tuned to a specific resonant frequency.

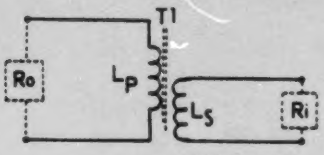

Figure 6-5. RF Transformer-Impedance Matching

6-33. For reasons of selectivity and sensitivity, it is desirable for the tuned circuits to have a relatively high Q. Sensitivity is the ability of an amplifier to detect and amplify small or weak signals. Recall that increasing X_L (2π FL) or decreasing R increases the Q. The core material of a transformer is one of the factors having a pronounced affect on the inductance. Increasing the permeability of the core material increases the inductance of the coil. Using a powdered iron core increases the permeability, and the required amount of inductance can be obtained with relatively few turns of wire. This leads to a small size transformer -- with low stray winding capacitance and high Q.

6-34. Miniature RF transformers are constructed so that a powdered iron core may be moved in and out of the area enclosed by the windings. This varies the permeability of the core, thereby varying the inductance. When a transformer is permeability-tuned, the capacitance of the tank is usually fixed in value. Some RF transformers, however, have both capacitive and permeability tuning, as shown in figure 6-4.

6-35. The Q of a transformer with no external load connected is called the "unloaded" Q. When used as an interstage coupling device, the primary of the transformer is shunted by the input resistance (Ri) of the following stage. This is illustrated in figure 6-5. The Q of the transformer with Ro and Ri connected is called the "loaded" Q. When "loaded," Q becomes

$Q = \frac{R}{X_L}$ (where R is the load impedance).

As R decreases (load increases), Q decreases. As Q decreases, bandwidth increases. It is obvious then, that changes in the load on a narrow band amplifier causes the bandwidth to change. If the load increases (R decreases), Q decreases and bandwidth increases. The opposite is also true; if the load decreases, Q increases and bandwidth decreases.

3-36. One of the functions of an interstage transformer is to match the large output resistance Ro of one stage to the low input resistance Ri of the next stage. This can be accomplished by selecting the proper turns ratio for the transformer primary (L_p) to the transformer secondary (L_s). As an example, consider the following: Assume that the output resistance (Ro) is 40 K ohms and the input resistance (Ri) is 2 k ohms. Use the formula:

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

With Ro and Ri as the impedance values:

$$\frac{N_p}{N_s} = \sqrt{\frac{Ro}{Ri}} = \sqrt{\frac{40 \times 10^3}{2 \times 10^3}} = \sqrt{20} = 4.47$$

Thus, in order to match the impedance of the two transistors and thereby achieve a maximum transfer of power, a transformer having a turns ratio of 4.47:1 is used for this case.

6-37. Another method of interstage coupling uses the tapped primary winding of a transformer. Since the selectivity of a circuit is primarily a function of circuit Q, a highly selective circuit requires a high Q. Q is a direct function of the inductive reactance and, therefore, the inductance present in the circuit. Thus, if the primary inductance (L_p) of an RF transformer can be increased without affecting the required turns ratio, the Q (and the selectivity) of the circuit can be improved. To maintain the original turns ratio and impedance of the winding, the number of turns in parallel with the transistor's collector must remain unchanged. This is accomplished by tapping the winding as shown in figure 6-6.

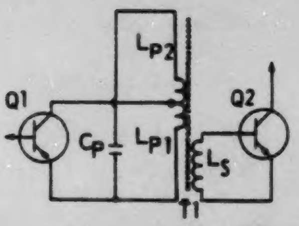

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Figure 6-6. Tapped Primary Transformer Coupling

6-38. If all the magnetic lines of L_{p1} cut L_{p2}, the total inductance of the primary is actually four times the inductance of L_{p1} alone. (Note: the computations use the following formulas: $Lt = L1 + L2 + 2M$, where $M = K \sqrt{L1 \cdot L2}$.

6-39. In order to maintain the original operating frequency the LC product must remain unchanged. Because the total inductance of the primary has been increased to a value four times the original, then the total capacitance of the primary (C_p) must be decreased to one fourth of its previous value.

6-40. Inductive coupling from the output of one transistor to the input of another can be accomplished with an autotransformer as shown in figure 6-7. The operation of these circuits is the same as for the circuit using a transformer with separated primary and secondary windings. Capacitance C_t (figure 6-7A) includes the output capacitance of Q1 and the shunt capacitance of the circuit. The tap at terminal 2 is positioned to provide impedance matching between the transistors.

6-41. If the inductance between terminals 1 and 3 (figure 6-7A) is too small to achieve a high Q for selectivity, the total primary inductance can be incresed many times by using the arrangement shown in figure 6-7B.

6-42. Another common interstage coupling arrangement is shown in figure 6-8. Capacitance coupling using split capacitors is also referred to as "Pi network." Matching the output impedance of Q1 to the input of Q2 is achieved by selecting the proper ratio of C1 and C2 (figure 6-8). C2 is normally larger than capacitor C1, which means the reactance of C2 is less than the reactance of C1. If the inductance of L1 (figure 6-8A) is too small to obtain a high Q for selectivity, the circuit shown in part B of the figure can be used. The capacitance can be decreased by a given factor to obtain the same resonant frequency.

6-43. In some applications a single-tuned stage will not meet the bandwidth requirement. Some applications may require a wider bandwidth. This requirement can be satisfied by the use of a double-tuned transformer. Double tuning refers to an interstage transformer in which both the primary and the secondary contain tunable resonant circuits.

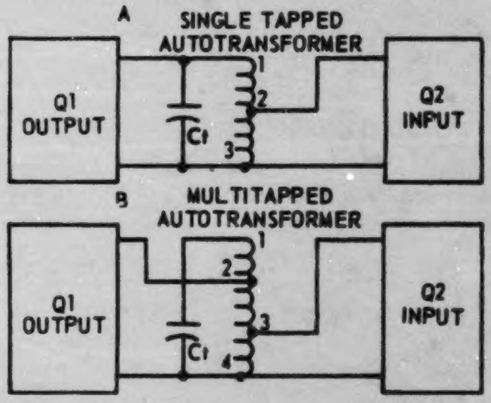

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Figure 6-7. Autotransformer Coupling

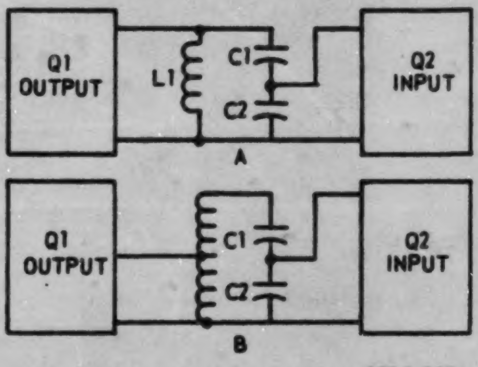

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Figure 6-8. Capacitance Coupling Using Split Capacitors

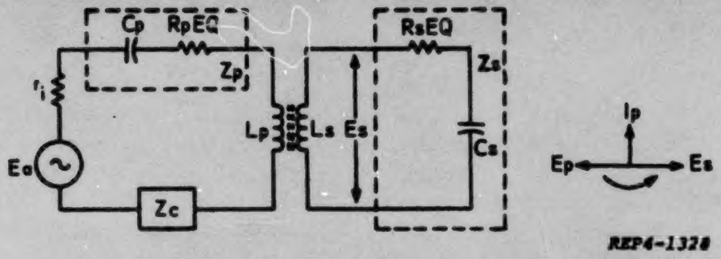


Figure 6-9. Double Tuned Transformer Equivalent Circuit

6-44. The bandpass characteristics of a double-tuned transformer are affected by the coefficient of coupling (K) between the primary and the secondary windings, the Q of the circuits, and the mutual inductance.

6-45. Although problems involving inductively-coupled circuits are very complex, they may be simplified if the following assumptions are made: (Refer to figure 6-9).

6-46. When a secondary circuit containing an impedance (Z_s) is coupled to a primary circuit, the effect is the same as if an equivalent impedance (Z_c), is referred to as the coupled impedance, is connected in series with the primary.

6-47. The secondary voltage (E_s) lags the primary current (I_p) by 90 degrees. The current (I_s) is that value of current that would flow in the secondary if the primary were removed and the induced voltage (E_s) applied in series with the secondary coil.

6-48. Applied voltage (E_a) and internal resistance (Ri) represent the voltage and resistance of the amplifier. R_pEQ is the series equivalent resistance of the primary circuit. Assume, for purposes of explanation, the Q of the primary and secondary circuits to be identical; both circuits are tuned to the same resonant frequency; and the amount of coupling between the circuits is variable (by physically moving the coils). Assume also that the Q of both circuits is held constant for all values of coupling.

6-49. The coupled impedance (Z_c) has the same phase angle as Z_s but is of the opposite sign. This means that when Z_c is reflected back into the primary, capacitive reactance in the secondary will appear as inductive reactance in the primary. If the secondary exhibits inductive reactance, it will appear to the primary as capacitive reactance. The total impedance of the primary will be the vector sum of the coupled impedance Z_c and the impedance of the primary circuit Z_p, considered by itself.

6-50. In a double-tuned transformer-coupled stage, the bandwidth characteristics depend (in part) on the amount of coupling. This can be shown by the use of the response curves in figure 6-10. The windings are first moved far enough apart so that very little coupling takes place (low value of K.) This condition is called "loose" coupling. With loose coupling, there is very little transfer of energy between the primary voltage and (E_s) is small because not all of the primary flux cuts the secondary to induce voltage.

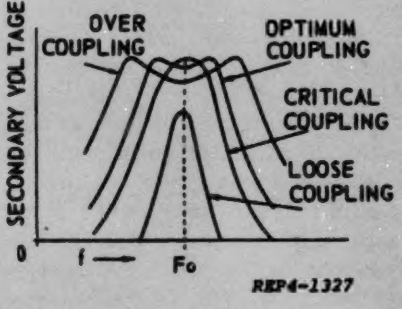


Figure 6-10. Double Tuned Transformer Response Curves

When K is small, the value of mutual inductance (M) is small. Due to the small amount of (M), the two circuits behave essentially as if they were separate tuned circuits. Except for the slope of the sides being slightly steeper, the response curve for loose coupling is the same as for a single tuned circuit.

6-51. As the coupling is increased (the circuits are moved closer together), the value of mutual inductance increases. This increases the amount of voltage induced in the secondary winding. The coupled impedance is also increasing and, due to its effect on the primary current, the response curve becomes wider. Thus, bandwidth increases.

6-52. As the coupling is further increased, Z_C, which is resistive at the resonant frequency, continues to increase. Eventually a value of coupling is reached where Z_C equals the equivalent resistance of the primary (R_pEQ, figure 6-9). This condition is called "critical" coupling. At this point, the reflected resistance matches the primary resistance. There is a maximum transfer of energy between the circuits. Thus, the induced secondary voltage is at its maximum value as shown in figure 6-10.

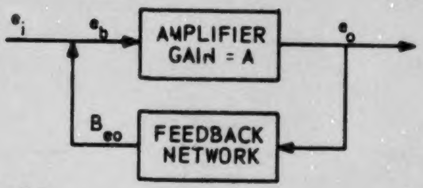
6-53. When coupling is increased beyond the critical value, the primary current at resonance begins to decrease. This is caused by the increase of the coupled impedance (reactances no longer cancel). The decrease in induced voltage is indicated by the dip in the response curve at F_O. Keep in mind that if the secondary circuit is inductive the reflected impedance coupled into the primary will be capacitive. Also, in a single-tuned circuit, the primary current begins to decrease at frequencies slightly above and below resonance. However, a different situation exists in a double-tuned circuit. At frequencies above resonance, the coupled impedance (Z_C) becomes capacitive and will cancel a portion of the primary inductance. This will, in effect, tune the circuit to a slightly higher frequency, or extend the resonant condition of the circuit slightly beyond F_O. A similar action takes place below resonance, where the coupled impedance appears inductive and adds to the primary inductance. This action extends the condition of resonance slightly below F_O. In any case, the result causes the primary current to remain high within the bandwidth. This is shown by the flat top of the "optimum coupling" response curve.

6-54. A continued increase in coupling will result in reduction of the gain at resonance and a further increase in the distance between the two resonant peaks (above and below F_O). The circuits are now said to be "over coupled." The overall response of the stage will take on the appearance of the double-humped curve in figure 6-10.

6-55. Feedback in Amplifiers

6-56. Feedback is defined as transferring energy from a high-level point back to a low-level point in a system. In other words, if the signal on the collector (high-level point) of a common-emitter amplifier is returned to the base (low-level point) it is called "feedback." In some cases, feedback is within the amplifier itself and in other cases feedback uses external circuitry.

6-57. There are two types of feedback: regenerative and degenerative. Regenerative feedback aids the input signal. Degenerative feedback, on the other hand, opposes the input signal. The principle of feedback can be illustrated by the block diagram in figure 6-11.



$$e_i + B_{eo} = e_b$$

$$A_{FB} = \frac{e_o}{e_i} = \frac{A}{1 \pm BA}$$

REP4-1325

Figure 6-11. Feedback

6-58. An input signal (e_i) is fed to an amplifier whose output signal is e_o. A portion of the output voltage (B_{eo}, where B is the percent) is fed back to the input by means of the feedback network. The actual input voltage to the transistor (eb) is the sum of the signal voltage (e_i) and the feedback voltage (B_{eo}).

6-59. The formula for gain is $A_{fb} = \frac{A}{1 \pm BA}$, where A_{FB} is the voltage gain of the amplifier with feedback, A is the voltage gain without feedback, and B is the percent of the output signal that is fed back. The denominator is 1-BA for regenerative feedback and for degenerative feedback the denominator is 1 + BA. If the amount of feedback is 5% and A = 10, solve to find that the gain with regenerative feedback is 20 and the gain with degenerative feedback is 6.6.

6-60. Regenerative feedback is used when a higher gain is required. However, this will reduce bandwidth and increase distortion. With a higher gain, it is easier for the amplifier to reach the operational limits (cutoff and saturation). Another consideration is the stability of the amplifier. When the regenerative feedback is large enough to make the denominator of the formula equal to zero (example: If B = 10% and A = 10. $A_{FB} = \frac{A}{1 - BA} = \frac{10}{1 - (10\%\ 10)} = \frac{10}{1 - 1} = \frac{10}{0}$), the circuit becomes extremely unstable and oscillates or generates its own signal. Some circuits operate on this principle but, for an RF amplifier, this is undesirable.

6-61. As we know, the transistor is not a one-way device. It conducts in two directions. Feedback takes place within the transistor through internal resistance and internal capacitance. Because tuned circuits are used in RF amplifiers, the effects of regenerative feedback must be eliminated. The means by which a circuit is made to transfer energy in only one direction is "unilateralization." Both the resistive and capacitive feedback must be cancelled in order to unilaterize a transistor amplifier.

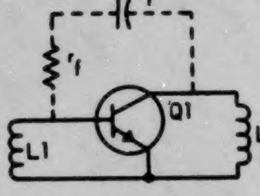


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Figure 6-12. Feedback Through a Transistor Amplifier

6-62. A simplified drawing of an RF amplifier is shown in figure 6-12. The dotted components (rf and cf) represent the internal resistance and capacitance between the base and collector of Q1. Resonant coupling circuits are used in the input and output. Since parallel resonant circuits act inductively below resonance, they are shown as L1 and L2. Due to the reactances of L1, Cf, and L2, the following situation may occur:

> The signal on the collector experiences a shift (L2 causes E to lead). The current fed back through Cf has a phase shift (C causes I to lead), and the feedback voltage developed across L1 has a phase shift (L1 causes E to lead.)

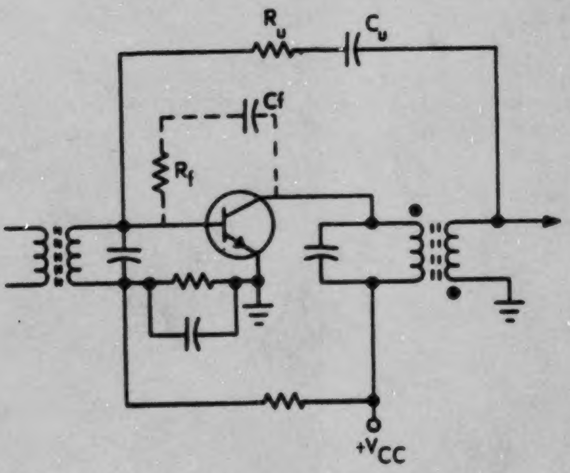

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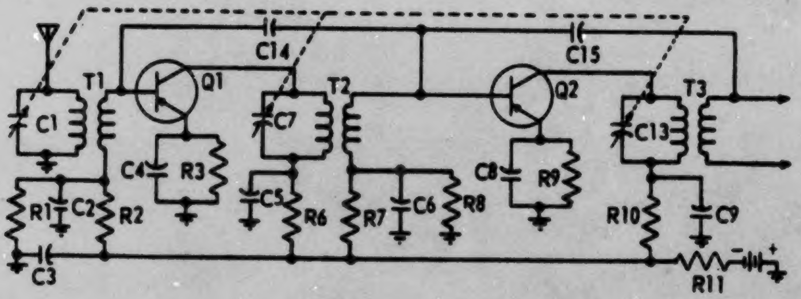
Figure 6-13. Unilateralized Tuned Amplifier



REP4-1330

Figure 6-14. Two-Stage RF Amplifier

6-63. The feedback voltage from the collector can experience a 180° phase shift which, when added to the amplifier's inversion (180°), appears on the base as regenerative feedback. The amplifier now becomes unstable and may begin to oscillate.

6-64. Many ways have been devised to "unilateralize" transistor amplifiers. This operation provides degenerative feedback to cancel the effects of regenerative feedback. Figure 6-13 shows a unilaterilized circuit consisting of two components, R_u and C_u. The values of R_u and C_u are so chosen that a signal of proper amplitude and phase will cancel the feedback through Rf and Cf.

6-65. In the schematic diagram of a two-stage cascaded RF amplifier in figure 6-14, notice capacitors C14 and C15. These capacitors are "neutralizing" capacitors and will compensate for the reactive feedback in the transistors. Since high-Q tuned circuits are used, some of the collector signal could pass through the interelement capacitance and produce regeneration. This causes circuit instability.

6-66. To compensate for this, a degenerative feedback network is used. C14, connected between the secondary of T2 and the base of Q1, feeds a small portion of the signal to the base of Q1. This signal will be opposite in phase to the signal that feeds internally from the collector to the base of Q1. If these two feedback signals are equal in amplitude and opposite in phase, they will cancel each other. The circut is now neutralized. The same action takes place with C15 neutralizing transistor Q2.

6-67. Another method of obtaining degenerative feedback is to use an unbypassed emitter resistor. With the emitter resistor unbypassed, the signal in the emitter opposes the signal and reduces the gain of the amplifier.

Chapter 7

WIDE BAND AMPLIFIERS

7-1. A very important factor in certain applications of an amplifying device is its ability to amplify a nonsinusoidal signal. A nonsinusoidal signal is one that does not vary at a sine wave rate. Nonsinusoidal signals, such as the sawtooth in oscilloscope sweep circuits, consist of a fundamental frequency with a large number of harmonics. To provide an output signal that is an exact reproduction of the input, the amplifying device must amplify the fundamental and all of the harmonic components equally. This type of amplifying device is referred to as a wide-band or video amplifier.

7-2. Square Wave Characteristics

7-3. To understand the need and purpose of a wide band amplifier, we must identify the composition of a nonsinusoidal wave. Let's use the square wave as a typical example. By definition, a square wave is a periodic wave which alternately assumes one of two fixed values, one positive and the other negative. The positive alternation has the same time duration as the negative alternation. One cycle of a square wave is composed of a negative alternation and a positive alternation. A perfect square wave has vertical sides and both the top and bottom are flat horizontal lines.

7-4. The sides of the square wave are fast changes from one value to another so they represent the high frequency components of a square wave. The flat tops and bottoms of a square wave have no variation (or a slow change) so they represent the low frequency components. Refer to figure 7-1.

7-5. A square wave is composed of a fundamental frequency and an infinite number of odd harmonics, in specific phase and amplitude relationships. To illustrate the frequency composition of a square wave, refer to figure 7-2.

7-6. One cycle of the fundamental frequency of a sine wave occurs in the same time period as one cycle of the square wave. They have the same frequency. The fundamental frequency of the square wave can be determined by substituting the time of one cycle in the formula $f = \frac{1}{T}$. The fundamental (sine wave) frequency is represented in figure 7-2B. The third harmonic is 3 times the

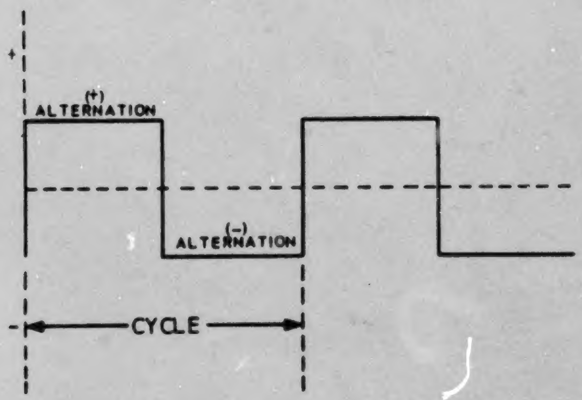


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Figure 7-1. Square Wave

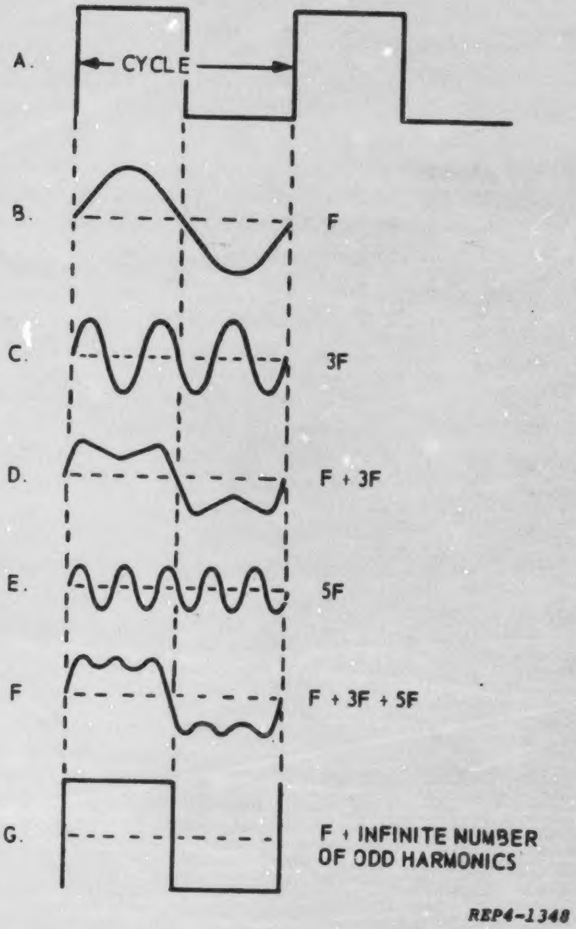

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Figure 7-2. Frequency Components of a Square Wave

fundamental frequency (figure 7-2C). By combining the fundamental frequency with the third harmonic, a resultant wave is derived (figure 7-2D). Notice that the leading edge of F and 3F are both going positive so they add. In the middle of the first alternation of the square wave, f is positive and 3f is negative so they subtract. On the second alternation, the same results are obtained except the polarity of f and 3f is reversed. Observe that the resultant wave (f + 3f, figure 7-2D) is beginning to look similar to a square wave.

7-7. The next odd harmonic, which is the 5th harmonic of f, is shown in figure 7-2E. When the 5th harmonic is added to the waveform of figure 7-2D, the resultant wave is shown in figure 7-2F. The resultant wave closely resembles a square wave. If this process is continued to infinity (that is, adding an infinite number of odd harmonics), the waveform becomes that of figure 7-2G, and we are back to the waveform made up of a very wide band of frequencies. If the square wave is to be amplified, the amplifier must be able to amplify all of the frequencies equally.

7-8. Another consideration of the square wave is the amplitude and phase of the harmonics. To have a perfect square wave, the amplitudes of the harmonics must have the following relationships: 3rd harmonic, one third of the fundamental; 5th harmonic, one fifth of the fundamental; and 7th harmonic, one seventh of the fundamental; etc. Further, the fundamental and all the harmonics must be in phase when the fundamental goes through zero. This is shown in figure 7-2, parts B, C, and E. When the fundamental frequency passes through zero and goes in a positive direction, all harmonics pass through zero and go in a positive direction. As long as the amplitude and phase relationships are maintained, the result is a square wave.

7-9. Wide Band amplifier Characteristics.

7-10. Two frequency response limitations must be overcome before a narrow band amplifier can be used for wide-band amplification. Figure 7-3 shows the limiting factors of an audio amplifier. The high-frequency response is limited by C_0 and C_1. C_0 represents the stray capacitance and the output capacitance of Q1, and C_1 represents the input capacitance of Q2. Since the reactances of C_0 and C_1 decrease as the frequency

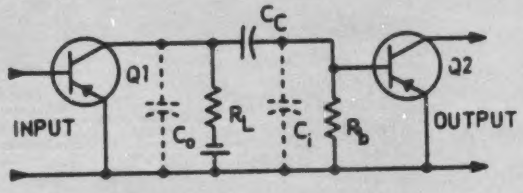

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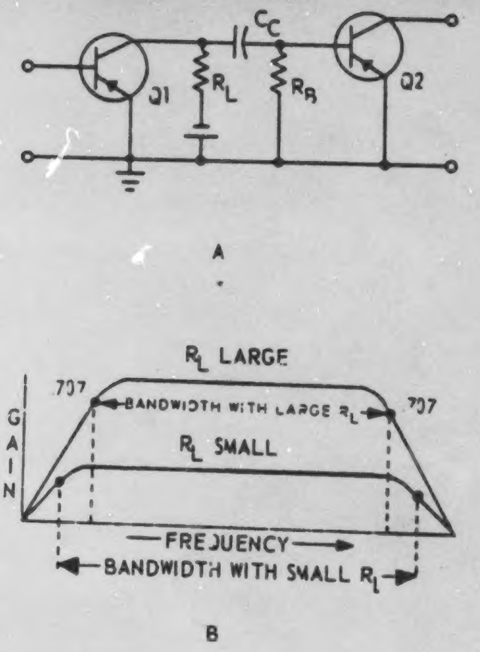
Figure 7-3. RC Coupled Amplifier Showing Capacitive Effect at High Frequencies


CC
Q1
RL
RB
Q2
A
RL LARGE
.707
BANDWIDTH WITH LARGE RL
.707
G
A
I
N
RL SMALL
FREQUENCY
BANDWIDTH WITH SMALL RL
B

REP4-1257

Figure 7-4. RC Coupled Amplifier and Response Curves

increases, the gain falls off as the frequency increases. The low-frequency response is limited by the coupling capacitor C_C. The reactance of C_C increases as frequency decreases, thereby reducing the gain for the low frequencies. The following discussion presents some of the methods used to increase bandwidth.

7-11. The frequency range of a video amplifier (typical wide-band amplifier) is from a few hertz to several megahertz. To be more specific, let's say we need a television video amplifier with a bandpass from 10 hertz to 4 megahertz. This is a typical range for a television video amplifier. One means of obtaining a wide bandwidth for a video amplifier is to use a small load resistor. Figure 7-4A shows a simplified schematic and figure 7-4B shows the frequency response when the load resistor (R_L) is large and small. With a large R_L, the gain of the amplifier is large and the half power points (.707) are closer together. By making R_L small, the half power point move farther apart and the bandwidth is wider. Of course, this method of widening the bandwidth sacrifices gain but making the load resistor smaller extends the high and low end of the response curve.

7-12. Two other methods used to extend the high frequency portion of the response curve (to 4 megahertz in our example) fall under the broad heading of high frequency compensation. The two methods are called shunt and series compensation, the names being derived by the component location in the circuit. Figure 7-5A shows a simplified schematic using shunt compensation.

7-13. For shunt compensation, inductor L1 is added in shunt with the output capacitance of Q1 (C_o) and the input capacitance of Q2 (C_i). Inductor L1 is connected in series with the load resistor, RL. At the high frequency end of the response curve, the reactances of C_o and C_i are very low. This reduces the impedance and causes the frequency

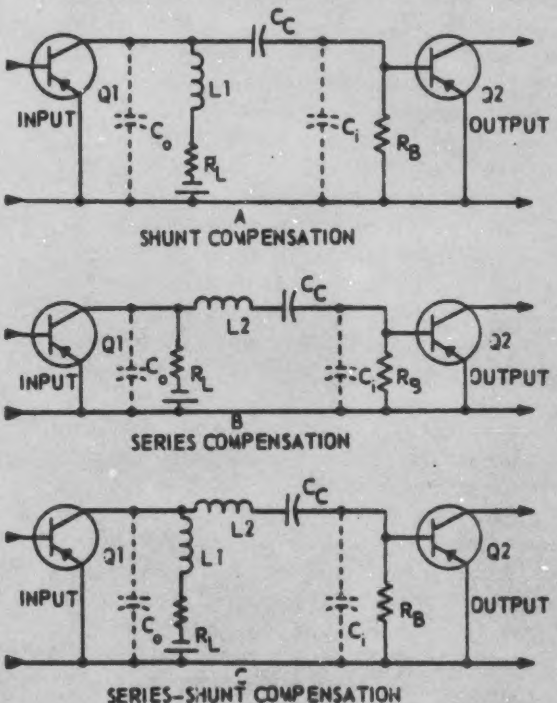

CC
Q1
L1
INPUT
Co
Ci
RL
RB
Q2
OUTPUT
A
SHUNT COMPENSATION
L2
CC
Q1
INPUT
Co
RL
Ci
RB
Q2
OUTPUT
B
SERIES COMPENSATION
L2
CC
Q1
L1
INPUT
Co
RL
Ci
RB
Q2
OUTPUT
C
SERIES-SHUNT COMPENSATION

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Figure 7-5. Wide-Band Amplifier High Frequency Compensation

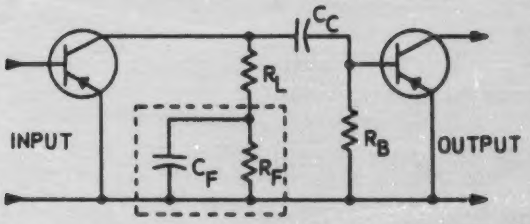

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Figure 7-6. Wide-Band Amplifier, Low Frequency Compensation

response to fall off. L1 will form a parallel resonant circuit with C_o and C_i at a frequency near the upper end of the response curve. One characteristic of a parallel tank at resonance is a high impedance. The addition of L1 thus raises the impedance of the circuit so that the gain does not fall off at the high frequency end. The Q of the circuit is relatively low (RL in series with L1), so the tank circuit will have a broad response. By proper selection of the component sizes, the response can be made to go beyond 4 megahertz. Because L1 is in shunt (parallel) with the signal path, this is called shunt compensation. L1 is also called a shunt peaking coil.

7-14. Series compensation is shown in figure 7-5B. Inductor L2 is added in series with the input capacitance of Q2. The inductor may be connected on either side of coupling capacitor C_C. Inductor L2 and capacitance C_i form a series resonant circuit at a frequency near the high end of the response curve. (C_C is a short at high frequencies). Characteristics of a series resonant tank circut are low impedance and high current, with maximum voltage across C_i. This compensates for the reduced high frequency gain. Again, if the proper size components are selected, the response of the video amplifier can be extended to 4 megahertz or more. Since L2 is in series with the signal path, it is called series compensation. L2 is also called a series peaking coil.

7-15. There are times when shunt and series compensation circuits are used at the same time. Figure 7-5C illustrates both a shunt peaking coil (L1) and a series peaking coil (L2). The discussions on shunt compensation and series compensation apply to this circuit.

7-16. Low Frequency Compensation

7-17. On the low frequency end of the frequency response curve, the input and output capacitances of the transistors have no effect. The low frequency response is limited by the coupling capacitor (C_C) and the input resistance of the transistor ($R_B + R_{eb}$). The time constant must be long to prevent phase distortion and loss of low frequency gain.

7-18. Phase distortion and loss of gain at low frequencies are minimized by adding a compensating filter network in series with the load resistor R_L (figure 7-6). This network consists of resistor R_F and capacitor C_F. It increases the collector load impedance at low frequencies because C_F has high reactance at low frequencies. Thus, the low frequency compensation network extends the frequency response curve to a much lower frequency. At high frequencies, C_F becomes practically a short and the collector load impedance is only R_L. Thus, the low frequency compensation network has no effect on the operation of the circuit at high frequencies.

7-19. Figure 7-7 shows a typical wide-band amplifier (10 hertz to 4 megahertz) using both high and low frequency compensation networks. The high and low frequency circuits operate independently and do not interfere with each other. At low frequencies the reactance of inductor L1 is very small and has no effect on the collector load impedance. The reactance of inductor L2 at low frequencies is also very small and has no effect on the coupling circuit. C1 and C3 are so large that they have no effect at low frequencies. Thus, high frequency compensation circuits have no effect at low frequencies. Similiarly, at high frequencies, the reactance of capacitor C2 is very small and practically short-circuits resistor R3.

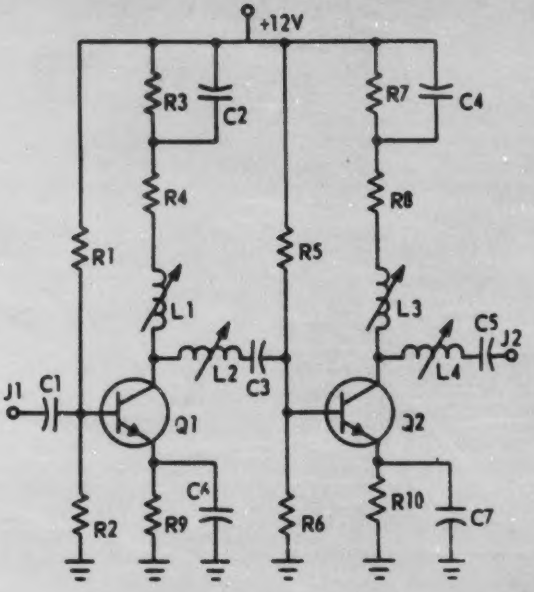
+12V
R1
R2
R3
C2
R4
L1
L2
C3
R5
R6
R7
C4
R8
L3
L4
C5
J2
J1
C1
Q1
Q2
C4
R9
R10
C7

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Figure 7-7. Compensated Wideband Amplifier

7-20. Stagger Tuning

7-21. Another method of increasing the bandwidth of amplifiers, is by use of "stagger tuning." In stagger tuning two transformer-coupled RF amplifier stages, the two circuits (one in each stage) are tuned above and below the center frequency.

7-22. Figure 7-8 shows a simplified diagram (power supplies and bias networks have been omitted) of a two-stage, stagger-tuned RF section. When tuned in this manner the stages are often called a "staggered pair."

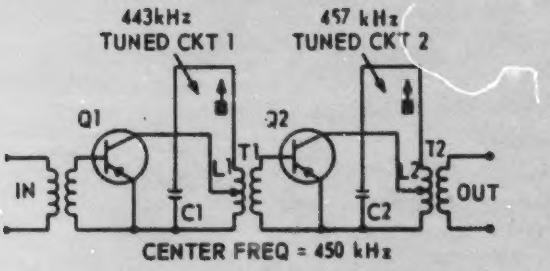
443kHz
TUNED CKT 1
457 kHz
TUNED CKT 2
Q1
Q2
IN
T1
L1
C1
T2
L2
C2
OUT
CENTER FREQ = 450 kHz

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Figure 7-8. Staggered Pair RF Amplifier (Simplified Schematic)

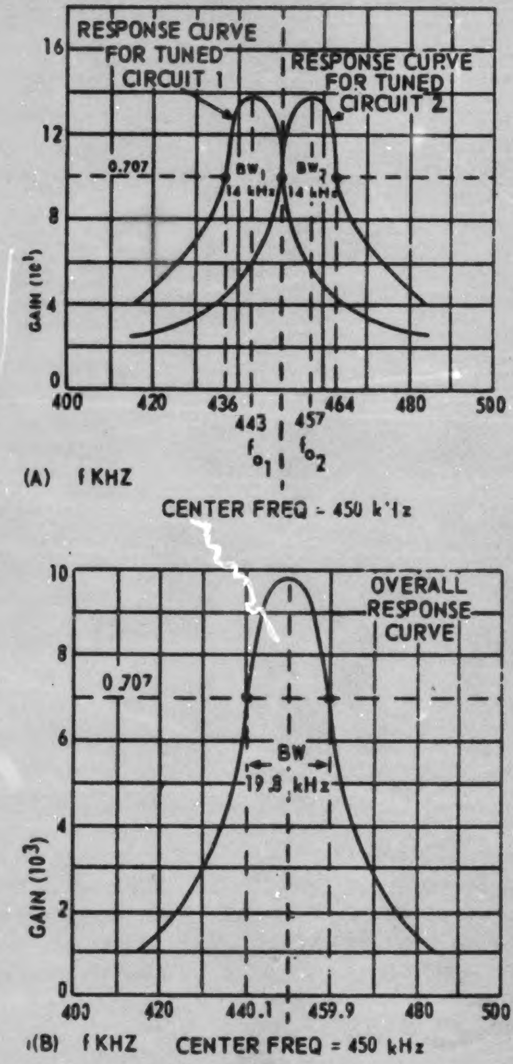

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Figure 7-9. Response Curves

7-23. Notice that although the center frequency is 450 kHz, circuit 1 (L1 and C1) is tuned to a resonant frequency of 443 kHz and circuit 2 (L2 and C2) is tuned to a resonant frequency of 457 kHz. Figure 7-9A illustrates the individual response curves of the two circuits. Circuit 1 is tuned below the center frequency by 7 kHz and its resonant peak is 443 kHz. This circuit is designed to have a

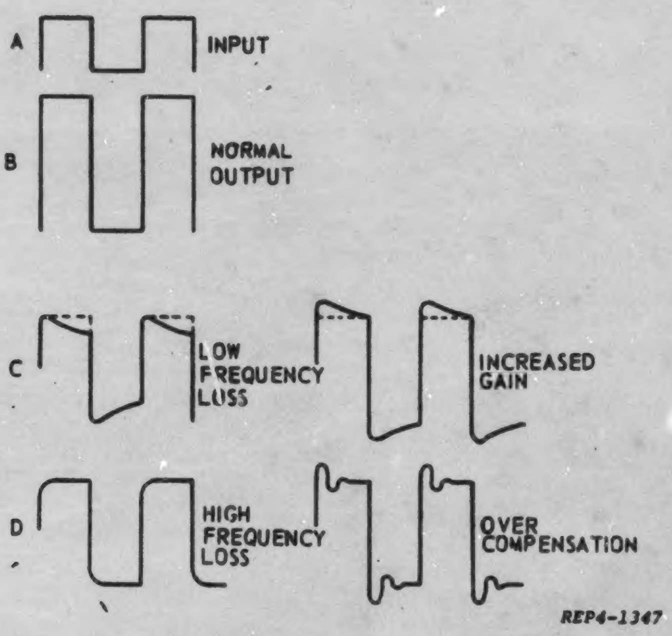

Figure 7-10. Wide-Band Amplifier Waveforms

bandwidth (BW1) of 14 kHz. This is evident by the fact that the .707 (half-power) points occur at 436 kHz and 450 kHz. Circuit 2 has its resonant peak at 457 kHz, 7 kHz above the center frequency. The bandwidth of this circuit is also 14 kHz. It might appear that the overall bandwidth of the staggered pair will be BW_1 plus BW_2, or 28 kHz. However, this is not the case.

7-24. One method of obtaining an overall response curve of two or more stages is to apply a number of frequencies to the input of the stages and plot the output amplitude for each frequency. When all those plotted points are connected together the result will be the overall response curve of gain-versus-frequency. Thus, the overall response curve of the staggered pair of amplifiers may be plotted from the individual response curves of figure 7-9A. The result of the plotting is shown in figure 7-9B. The upper half-power point now occurs at a frequency of 459.9 kHz and the lower at 440.1 kHz. The bandwidth is now 19.8 kHz. The end result is that stagger tuning will give a wider bandwidth than tuning each circuit to the same frequency.

7-25. Troubleshooting

7-26. Before you can find a trouble in a circuit, you must understand the circuit's operation. Figure 7-10 shows the waveforms for figure 7-7. The input square wave (A) is applied at J1 and the output waveform (B) is taken from J2. Since two common emitter amplifiers are used, the input and output signals are in phase. This represents correct operation, since no distortion is present and the signal has been amplified.

7-27. Suppose there is no output at J2. There are many reasons for this, some of which we discussed earlier, such as transistors open or shorted, or coupling capacitors open. Also, open components L1, R3 or L2 could cause no output.

7-28. Observe the waveform labeled LOW FREQUENCY LOSS in figure 7-10C. Notice that the wave is no longer square; it is "tilted." The tilted top and bottom indicate that an RC time constant is not long enough (the wave is approaching differentiation.) What can cause these symptoms? Refer to figure 7-7; R3, R7, C4, or C2 may be shorted.

An open C2 or C4 will produce a symptom that is easily mistaken for a shorted C2 or C4. Close examination of the curve labeled INCREASED GAIN will reveal the difference. Note that amplitude has increased for the leading edge but not for the trailing edge.

7-29. The waveform labeled HIGH FREQUENCY LOSS is approximately the correct amplitude, but the leading edges are "rounded off." This means that the high harmonic frequencies are being lost. The malfunctioning components that could cause this include shorted L1, L2, L3, or L4.

7-30. In practical circuits, the inductors are often variable and will require adjustment by the maintenance technician. Maladjustment can produce the waveforms labeled HIGH FREQUENCY LOSS and OVERCOMPENSATION.

7-31. In summary, a nonsinusiodal wave contains a fundamental frequency and a number of harmonics. Since these frequencies must receive the same amount of gain, a wideband amplifier is required.

7-32. The low frequency components of a square wave are represented in the top and bottom. The circuits that can distort the low frequencies are the coupling capacitors. Low frequency compensation networks are used to prevent low frequency distortion.

7-33. The high frequency components of a square wave are represented on the sides. Interelement and distributed capacitance can attenuate the high frequencies. High frequency compensation components, which prevent high frequency attenuation, include shunt and series peaking coils.

Chapter 8

SATURABLE REACTORS AND MAGNETIC AMPLIFIERS

8-1. Another practical application of the principle of inductance is the saturable reactor. This chapter applies principles of magnetism and explains the magnetic circuit, core saturation, and the hysteresis loop. Then, we discuss the operation of a simple saturable reactor.

8-2. In electrical circuits, voltage and current are the basic electrical variables. In the magnetic circuit, the magnetic variables are magnetomotive force (MMF) and flux (ϕ). Magnetomotive force is the basic magnetic potential or pressure; it is the force necessary to create a magnetic field. MMF is determined by the number of turns of a coil times the current flow, often referred to as ampere-turns (NI) of a coil. If three amperes of current flow through three turns of wire, shown in Figure 8-1, the MMF is nine ampere-turns.

8-3. The flux (ϕ) of a magnetic circuit is the total number of lines of magnetism in the magnetic circuit. Flux compares with current in an electrical circuit. Just as current increases with voltage when resistance remains constant, the number of flux lines increases as the MMF increases, if the flux path remains fixed.

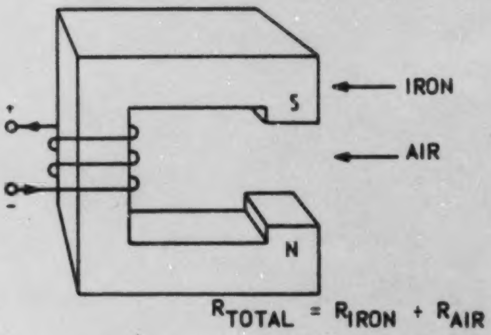

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Figure 8-1. Total Reluctance of a Magnetic Circuit

8-4. The third property of a magnetic circuit is reluctance. Reluctance (R) opposes the creation of magnetic flux within the coil. If the reluctance increases, the magnetic flux decreases when the magnetomotive force remains constant. Let's compare the electrical circuit with the magnetic circuit:

Electric: $R = \frac{EMF}{I}$

Magnetic: $R = \frac{MMF}{\phi}$

where:

R = reluctance or opposition to flux buildup,

MMF = magnetomotive force (NI), and

ϕ = number of magnetic lines.

8-5. The reluctance of a magnetic circuit is directly proportional to the length and inversely proportional to the permeability (μ) and cross-sectional area of the magnetic path, as shown in the formula $R = \frac{l}{\mu A}$. Where materials of different permeability make up the magnetic path, reluctance must be determined for each portion of the path and added. For example in figure 8-1, the total reluctance equals the reluctance of iron plus the reluctance of air.

8-6. Recall that permeability is a measure of the ability of a material to act as a path for magnetic lines of force. By definition, air has a permeability of one, because one unit of magnetizing force produces one flux line per unit area. In contrast, permeability of iron is 50 to 2000. This means that one unit of magnetizing force causes 50 to 2000 flux lines per unit area when compared to the permeability of air.

8-7. The permeability of any material may be expressed by the following ratio:

$$\mu \text{ (mu)} = \frac{B \text{ (flux density)}}{H \text{ (magnetizing force)}}$$

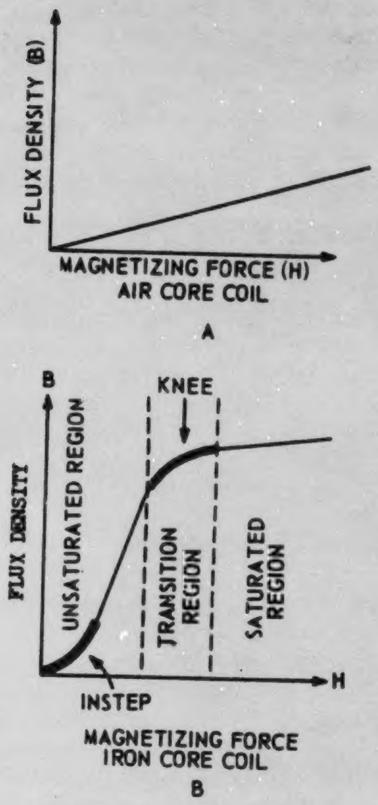

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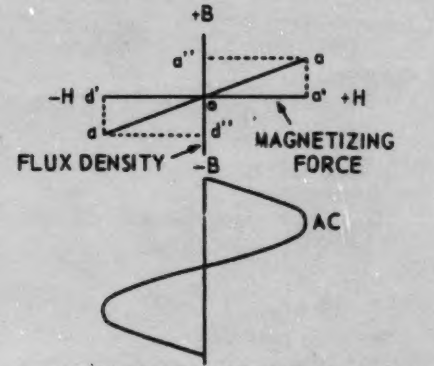
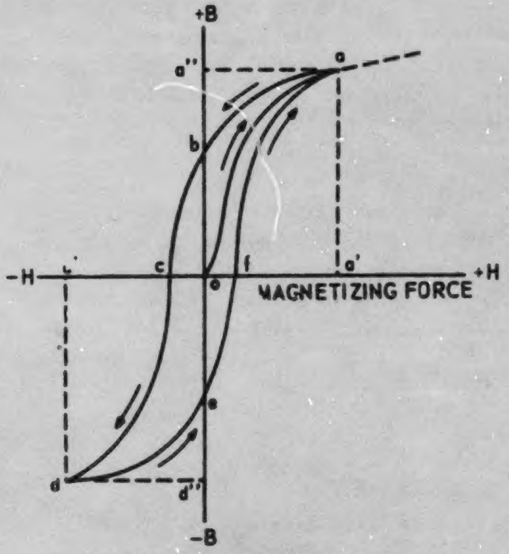
Figure 8-2. Permeability Comparison Graph

This ratio is often referred to as the B-H ratio, and it is used as a basis for selecting core materials for saturable reactors. Core materials used in saturable reactor circuits are capable of producing high values of flux density (B) with low values of magnetizing force (H). H is directly proportional to MMF and is the magnetic potential drop per unit length of core, which compares to the voltage drop per unit length in the electrical circuit. Any change in the ampere-turns of a coil will cause a proportional change in magnetizing force H. Flux density B is the number of lines of force per square unit area measured in a plane perpendicular to the direction of the magnetic field.



A - B-H PLOT OF ALTERNATING FLUX IN AN AIR CORE COIL



B - B-H PLOT OF ALTERNATING FLUX IN IRON CORE COIL

REP4-1333

Figure 8-3.

8-8. You know that in a given electromagnet (coil), as the magnetizing force increases, flux increases. We can plot this as shown in figure 8-2. Notice that with an air core the flux density increases in a straight line, at a constant rate, with an increase in magnetizing force. The high reluctance and the low permeability of air in the magnetic circuit requires a high magnetizing force to cause many flux lines. Quite the contrary when we have an iron-core -- the ratio of B to H is now a complex curve. Note, by the shape of the curve, that the permeability characteristics of the iron core are not constant, but vary as the magnetizing force increases. Other factors that affect the shape of the magnetization curve are heat and purity of the material.

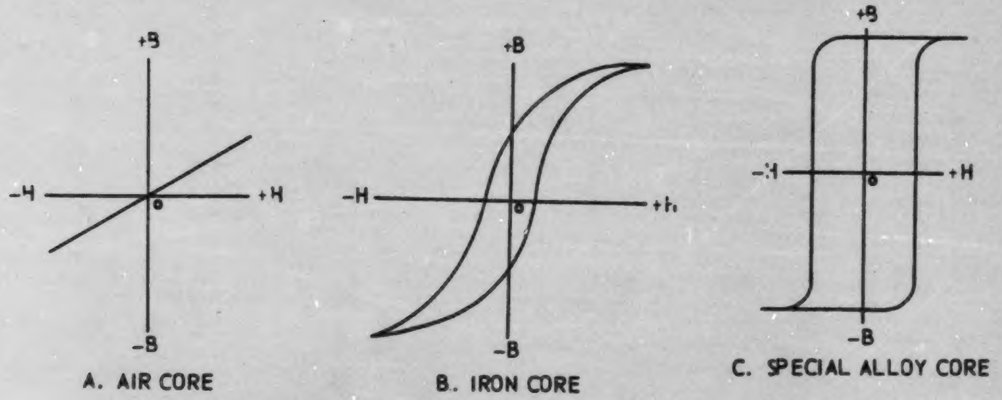
8-9. Figure 8-2 uses direct current as the magnetizing force. Alternating current forces a further look at what happens in an electromagnet. Recall that the sine wave of current reaches a peak amount in one direction, decreases to zero, and then flows in the opposite direction. Refer to Figure 8-3A for a study of AC applied to an air-core coil. Applied AC increases to its peak value and magnetizes the coil to point a. As current decreases to zero and reverses direction, magnetizing force and flux density decrease to zero and reverse direction. As magnetizing force increases in either direction, flux density increases and decreases to form the straight line graph at the top of figure 8-3A.

8-10. With an iron-core, however, we have a curved line. As the magnetizing force reaches its first peak value at point a' in figure 8-3B, the iron core reaches maximum flux density at point a''. As the magnetizing force decreases to zero, magnetic strength also decreases, but a "residual" magnetism stays in the core. When the magnetizing force is at zero, the flux density of the residual magnetism is at point b.

8-11. When the magnetizing force is applied in the opposite direction, H must reach point c before flux density returns to zero. The mangetizing force required to cancel the residual magnetism is called COERCIVE FORCE. A coercive force from point o to point c is needed to reduce the flux to zero. As H continues increasing to point d', the flux density increases to point d''. The return of the magnetizing force to zero results in a reduction in flux but, as before, B does not return to zero. Flux density decreases to point e, and a coercive force from point o to point f is needed to reduce the flux to zero. The plotted cycle of magnetization (a, b, c, d, e, f, a), shown in figure 8-3B, is called a "hysteresis loop."

8-12. The general effect where flux density lags the magnetizing force is called hysteresis. We defined this term in an earlier chapter. Energy is lost because a portion of the magnetizing force is used to overcome the residual magnetism. The area within the hysteresis loop is proportional to the amount of work done against the residual magnetism of the core and represents the power loss. The amount of loss involves the type of core material and the frequency of the magnetizing force.

8-13. Figure 8-4 shows three hysteresis loops of coils with cores of different amounts of retentivity. The air core has no retentivity and the iron core retains some residual magnetism. The ideal saturable reactor core is made of a special alloy which



A. AIR CORE B. IRON CORE C. SPECIAL ALLOY CORE

Figure 8-4. Hysteresis Loops of Various Core Materials

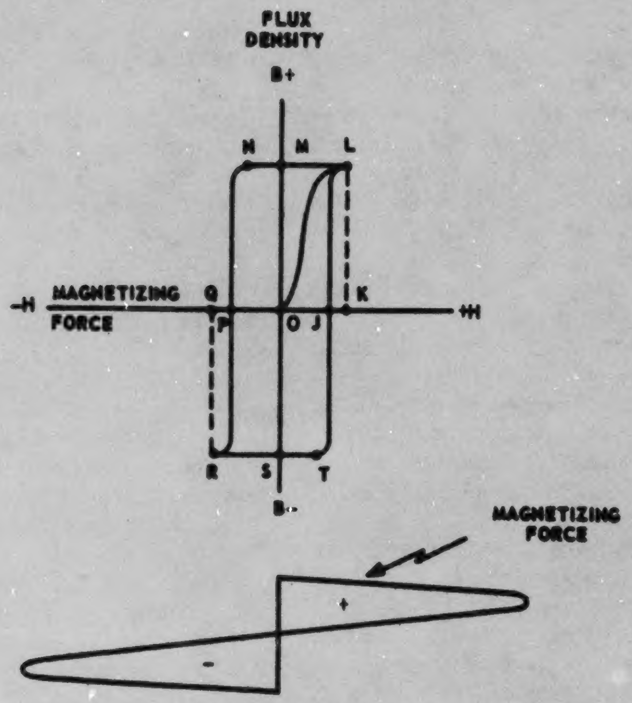

FLUX DENSITY
B+
N
M
L
-H
MAGNETIZING FORCE
Q
P
O
J
K
+H
R
S
T
B-
MAGNETIZING FORCE
+
-

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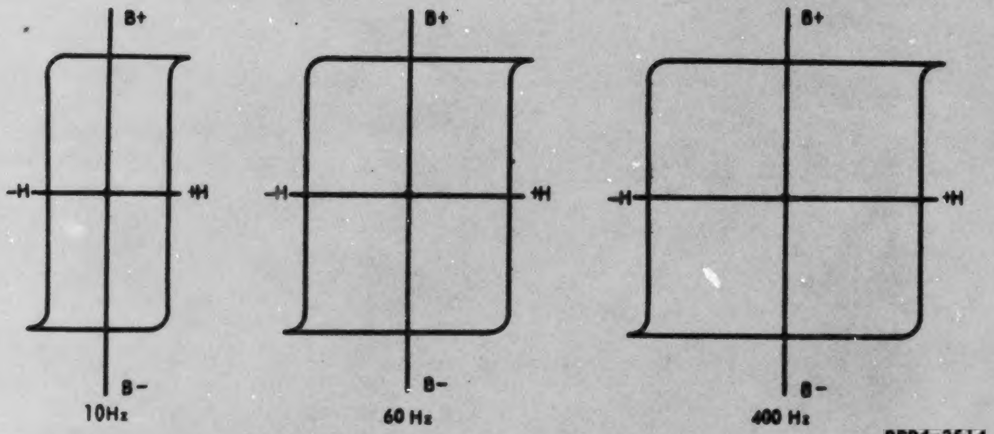
Figure 8-5A. Hysteresis Loop for a Saturable Reactor


B+
-H
+H
B-
10Hz
B+
-H
+H
B-
60 Hz
B+
-H
+H
B-
400 Hz

REP4-2514

Figure 8-5B. Hysteresis Loop at Different Frequencies

remains saturated until the coercive force cancels and reverses the direction of flux lines.

8-14. The high degree of rectangularity of the loop (figure 8-4C) shows that the core has a quick transition between positive and negative saturation. The narrowness of the loop shows the amount of coercive force needed to overcome the residual magnetism to be very small and it also indicates that a small magnetizing force can cause core saturation. The ideal hysteresis loop for saturable reactors is rectangular in shape and very narrow in width.

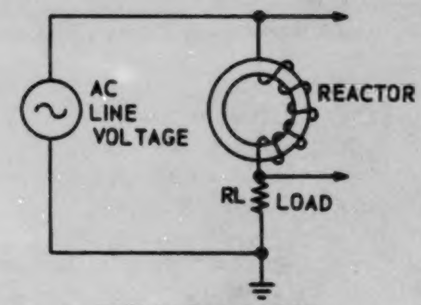
8-15. The hysteresis loop shown in figure 8-5A is typical of that for the saturable reactor. The saturable reactor is an inductor with a special type of core which can be saturated with a small magnetizing force. Notice that as the magnetizing force (+H) is increased from point O to point K, the flux density (B+) is increased from point O to point L. Point L represents maximum flux and the core is at saturation. The saturable reactor core has a high permeability. That is, a small magnetizing force will cause core saturation. The saturable reactor also has the property to stay magnetized and saturated even though the magnetizing force is removed. In figure 8-5A, note that as the magnetizing force returns to point O, the flux density remains at point M which still represents maximum flux or saturation. The amount of residual magnetism indicates that the saturable reactor has a very high retentivity. The saturable reactor remains at saturation until a magnetizing force of the opposite polarity (-H) is applied. When the magnetizing force reaches point P, the core suddenly becomes demagnetized and the flux density is zero. The magnetizing force represented by the magnitude O to P is the coercive force. The coercive force needed to desaturate the core of the saturable reactor is small.

Thus far, we have seen that a small magnetizing force (O to K) will saturate the core. The core will remain saturated at point L, M, and N until a small coercive force (O to P) demagnetizes the core. When the magnetizing force is increased to point Q, the core will saturate once again but in the opposite polarity. The core will remain saturated as represented by points R, S, and T until a coercive force from O to J is applied. At point J, the core is once again demagnetized. Increasing the magnetizing force to point K will once again saturate the core and the cycle is repeated. When the saturable reactor is in its saturated state, the coil will offer minimum reactance to an alternating current (AC). Prior to saturation, the coil has a very high reactance to AC. Due to these core characteristics, the saturable reactor can be switched from high to low reactance by small levels of magnetizing or coercive forces. This enables the saturable reactor to be used as a switching device. One of the factors which changes the level of magnetizing force, necessary to switch the reactor, is the frequency of applied voltage. Notice in figure 8-5B, that as the frequency of the applied voltage is increased, larger magnetizing and coercive forces are needed. This is due to the fact that at higher frequencies, greater power loss occurs in the reactor and a greater force is needed for switching.

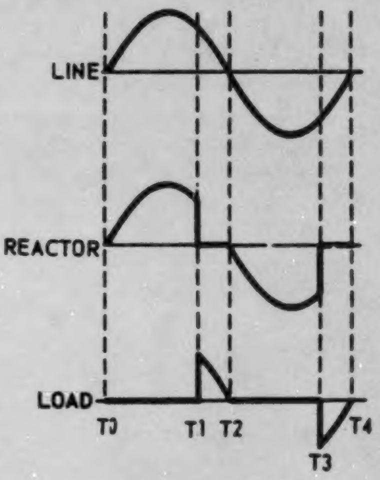
8-16. Early shapes of the saturable reactor core were very similar to that of the conventional transformer. The transformer core is still used in some applications but it is often replaced by the ring-shaped or toroidal core.

8-17. Figure 8-6A shows a simple saturable reactor circuit. A toroidal coil reactor in series with a resistor (RL) is driven by a sinusoidal line voltage.

8-18. The saturable reactor functions as a synchronous switch because the impedance of the reactor changes abruptly from a high impedance to a low impedance during each half-cycle of applied line voltage. The point at which the impedance change occurs is determined by the core characteristics. When the core of the reactor is unsaturated, the impedance of the reactor is very high compared to the load impedance. During this time, the reactor acts as an open switch and very little power reaches the load



A. SIMPLE LOAD CIRCUIT



B. VOLTAGE WAVESHAPES

REP4-1336

Figure 8-6. Saturable Reactor Simple Circuit

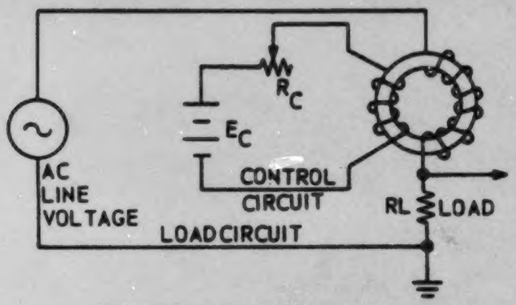
from the AC line. When the core of the reactor becomes saturated, the impedance of the reactor acts as a closed switch and the full line voltage is impressed across the load resistance. The change from one impedance level to the other is rapid, and it is repeated with every half-cycle of the applied line voltage.

8-19. Figure 8-6B shows the voltage waveshapes developed across the load resistor and the reactor for one cycle of applied line voltage. In this example, the line voltage is considered to be of sufficient amplitude to drive the core into saturation on each half-cycle. At time T0, line voltage is applied. As voltage increases in the positive direction, magnetizing force increases, and flux density in the core increases to saturation. The current flow through the load between T0 and T1 is very low. The amplitude of current at this time is determined by the width of the hysteresis loop; this current and the number of turns in the coil (NI) determine the magnetizing force (H). During this interval, the impedance of the reactor is very high compared to the resistance of the load. As a result, most of the line voltage is dropped across the reactor.

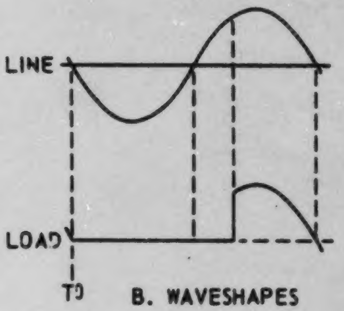
8-20. At T1, flux density reaches maximum and the core saturates. At the instant the core saturates, the high impedance of the reactor drops to a low value, and a heavy surge of current causes an instantaneous rise in voltage across the load resistor. During the time interval between T1 and T2, useful power is delivered to the load from the line voltage supply.

8-21. At T2, line voltage reverses polarity and current flow changes direction. The impedance of the reactor is once again high, and a low value of magnetizing current flows, as in the positive half-cycle. Because of the high impedance of the reactor compared to the low impedance of the load, most of the line voltage is dropped across the reactor between T2 and T3. At T3, flux density reaches its maximum value and the core again becomes saturated. At this instant, the impedance of the reactor drops rapidly from a high value to a low value. The heavy surge of current again causes nearly all of the line voltage to appear across the load. For the remainder of this half-cycle, useful power is delivered to the load. At T4, the polarity of the line voltage reverses, and the action just described repeats as it does with every cycle.

8-22. When the core is saturated and no additional flux density is possible, further increase in magnetizing force causes no change in flux. Thus, no counter EMF or opposition resulting from a change in flux takes place. At this time. the only opposition of the reactor coil is its DC resistance and the load receives useful power.



A. SATURABLE REACTOR CIRCUIT



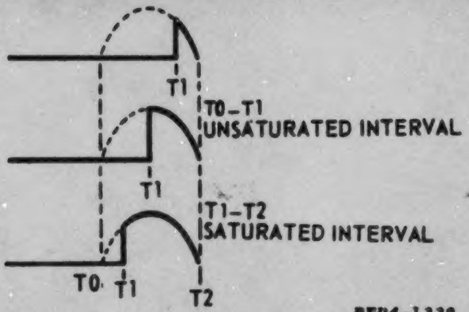
B. WAVESHAPES

REP4-1337

Figure 8-7. Saturable Reactor with DC Control

8-23. Another circuit must be added to figure 8-6A to establish control over the time that core saturation occurs. Refer to figure 8-7A. A DC source is connected to a control winding on the toroidal coil. Adjusting resistor R_C controls the instant that core saturation occurs and, thus, controls the average power delivered to the load. A small power source controls a large power source; this demonstrates amplifier action.

8-24. The saturable reactor circuit consists of two windings. One is the control coil and the other is the load coil. A direct-current source applies magnetizing force for the control coil. Variable resistor R_C controls this steady magnetizing current. The toroid is thus magnetized with one polarity to a desired flux density, which determines when the core becomes saturated.



REP4-1338

Figure 8-8. Load Waveshapes for Different Values of Control Current

8-25. The voltage waveshape developed across the load resistance in one cycle of line voltage is shown in figure 8-7B. When AC line voltage is applied, notice that the coil reaches saturation on the positive swing but not on the negative swing. Thus, the AC circuit has high impedance for all of the cycle except that portion of the positive half-cycle when the core saturates.

8-26. The DC control current establishes control over the time that the reactor is saturated. Figure 8-8 shows the load waveshapes of a saturable reactor circuit, with different values of control current. If the control current is increased, core saturation occurs sooner. This causes the time reference T1 to move toward T0, the core saturates for a longer period of time, and the average current delivered to the load increases. If the control current is decreased, the time reference T1 is moved toward T2, and the core is saturated for a shorter period of time. A decrease in control current results in less current being delivered to the load. The time at which the core becomes saturated is set by the control current which, in turn, determines the output of the saturable reactor. The basic principles of saturation control are the same for all saturable reactors. The only difference that might exist is the arrangement of the control circuit.

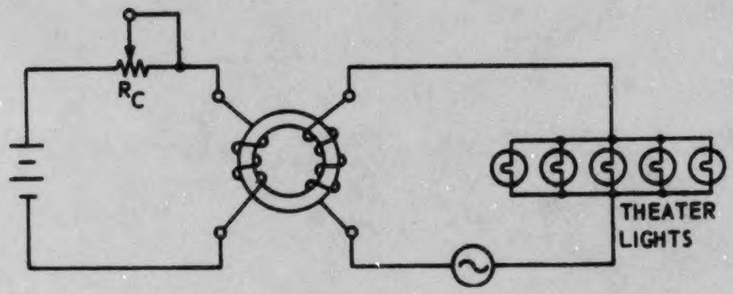

R_C
THEATER LIGHTS

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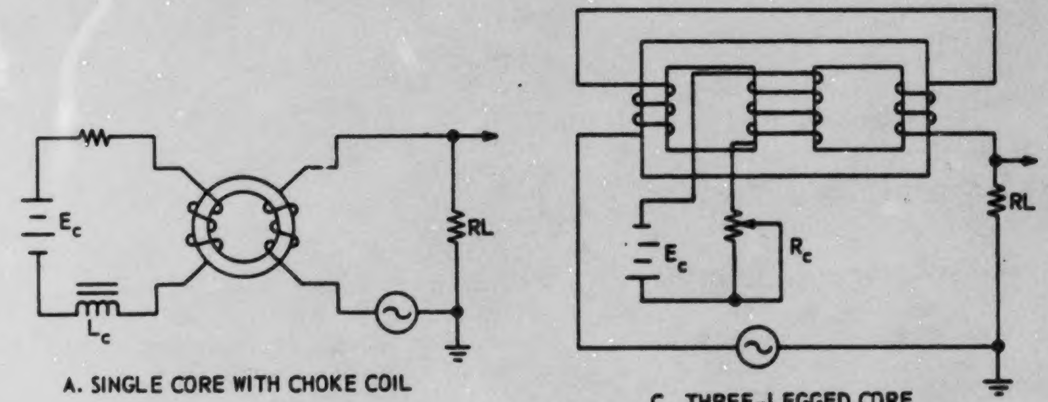
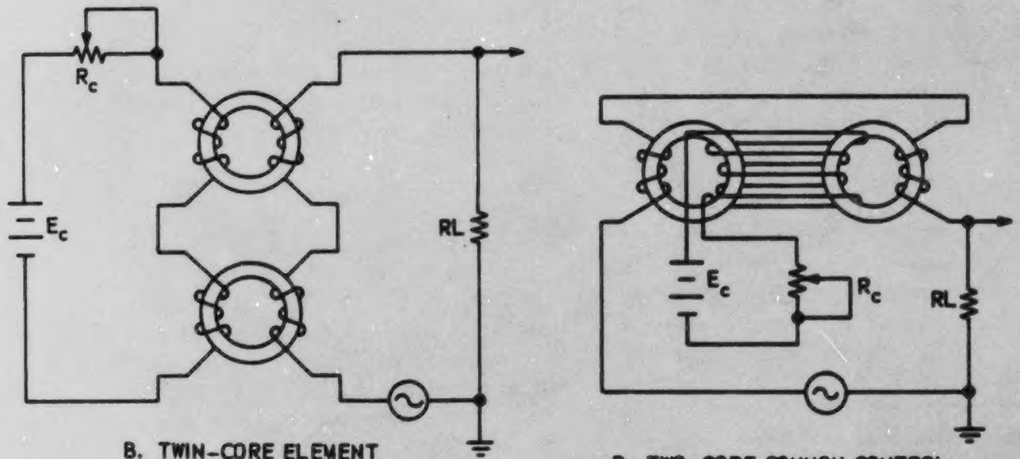
Figure 8-9


E_c
L_c
RL
E_c
R_c
RL

A. SINGLE CORE WITH CHOKE COIL

C. THREE-LEGGED CORE


R_c
E_c
RL
E_c
R_c
RL

B. TWIN-CORE ELEMENT

D. TWO-CORE COMMON CONTROL

REP4-1339

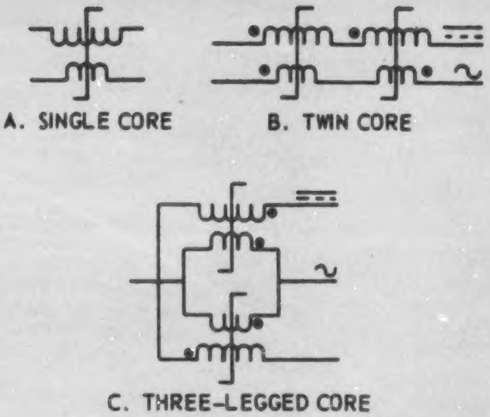
Figure 8-10. Methods of Eliminating Transformer Action

8-27. Figure 8-9 shows a very simple application of the saturable reactor to control brightness of theater lights. R_C is adjusted to set the amount of current through the lights, the longer the saturated interval, the higher the average current and, therefore, the brighter the lights in the theater.

8-28. The saturable reactor is simple, rugged, and reliable. It is capable of driving many loads and can handle large quantities of power with good efficiency.

8-29. Transformer action occurs between the load coil and the control coil. This transformer action lowers the efficiency of the circuit. The saturable reactor, shown in figure 8-7, is designed with a very high impedance in the control circuit. The purpose of the high impedance is to reduce control-circuit currents induced from the load coil. This keeps the impedance of the reactor high and load power low when the reactor is unsaturated. If the impedance of the control circuit is low, a large current is induced from the load coil, which causes load current to be large prior to core saturation. This seriously reduces the gain of the saturable reactor.

8-30. There are other methods used to reduce or, in some cases, practically eliminate the induced currents from the load coil. Some of the common methods used are shown in figure 8-10. Illustration A shows a single-core saturable reactor with an iron-core choke coil in the control circuit. The purpose of the choke coil is to present a high impedance to alternating currents so that the voltage induced from the load coil into the control coil produces only small circulating currents in the control circuit. Another method of eliminating undesired effects of transformer action between load winding and control winding is shown in figure 8-10B. This method consists of using two separate core elements, sometimes referred to as a twin-core arrangement. The control windings are series aiding, while the load windings are series opposing. The voltage induced into one of the control windings is cancelled by an equal but opposite voltage induced into the second control winding. A saturable reactor such as this can operate effectively with a wide range of control-circuit impedance. The same effect as described above for the series-connected control windings can be achieved with a common control winding, as shown in C and D of figure 8-10. In both cases, the load coils are wound so that they are series aiding. The voltages induced into the control coils from the load coils are of equal amplitude but opposite polarity. The result is a cancellation of the induced currents.



REP4-1341

Figure 8-11. Saturable Reactor Symbols

8-31. Figure 8-11 shows saturable reactor schematic symbols which correspond with pictorial diagrams in figures 10A, B and C. The specific symbol indicates the number and types of windings. The power winding has 3 loops and the control winding has 5. The line across the windings represents saturable core magnetic winding.

8-32. Figures 8-11B and C have kind-of-current (DC or AC) and polarity (dots) markings. The dots placed near one end of each coil show relative polarity of the windings. An increase of current entering the end of the control winding marked with a dot causes an increase in the power output. If instantaneous currents enter the windings at the marked points, they will produce aiding fluxes.

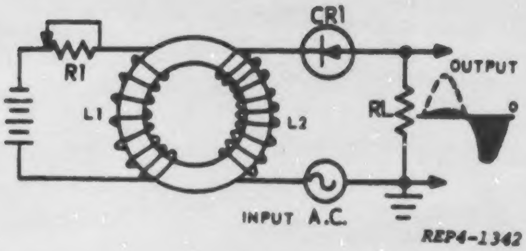


Figure 8-12. Half-Wave Magnetic Amplifier

8-33. Magnetic Amplifiers

8-34. A transistor can function as an amplifier because of its ability to produce large power changes in its output circuit with only small changes of power in its input circuit. In the saturable reactor, small power changes in the control circuit produce large power changes in its load circuit. The saturable reactor can therefore function as an amplifier. The amplifier which employs the saturable reactor as its amplifying device is called a MAGNETIC AMPLIFIER. The magnetic amplifier is very rugged, reliable, and capable of controlling large amounts of power. In addition, it is able to produce large variable positive DC, negative DC, or AC power outputs with small DC input power changes. Because the power output from the amplifier is variable, the magnetic amplifier is sometimes used for motor speed control, or other power control applications. DC outputs can be used for the directional control of motor rotation.

8-35. The schematic for the basic half-wave magnetic amplifier is shown in figure 8-12. The saturable reactor in the amplifier is composed of L1 and L2. L1, R1, and the battery make up the control circuit which determines the amount and direction of control flux through the reactor core. The output load circuit is composed of L2, CR1, RL, and the AC power source. One function of the diode is to block the generation of opposing magnetic flux in the core which would generate heat and decrease efficiency. Power will be delivered to the load (R_L) when the control and load magnetic fields are aiding and the core saturates. The amount of power delivered to the load is controlled by the amount of flux produced by the control winding, L1. The greater the control flux, the more power output to the load. The polarity of the output voltage developed across the load is determined by the direction of the control flux in the core and the polarity of the diode in the load circuit. Note that the amplifier in figure 8-12 is producing a direct current through the load. The voltage output is shown as a negative pulse which will average out to a DC level. If either the diode or the control voltage were reversed, the circuit would not have an output (see figure 8-13). However, if both the battery and diode were reversed, the amplifier would produce a positive DC output as shown in figure 8-14.

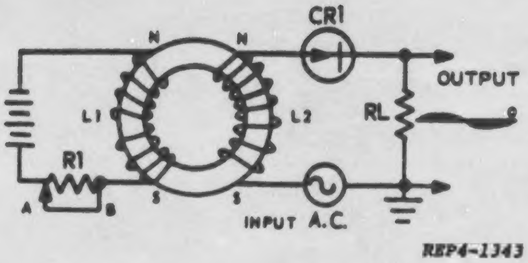


Figure 8-13. Half-Wave Magnetic Amplifier, No Output

8-36. To determine the output of a magnetic amplifier the following steps may be employed. The first step is to use the LEFT-HAND THUMB RULE to determine the direction of the magnetic field set up by the control winding. To use this rule, both the direction of current and coil turns must be considered.

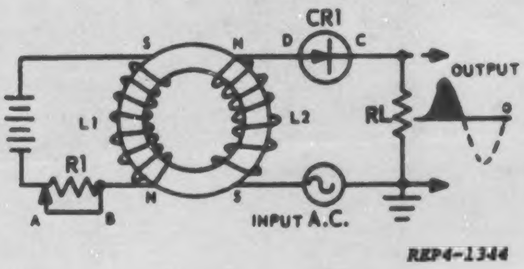


Figure 8-14. Half-wave Magnetic Amplifier, Positive Output.

Figure 8-14 shows the first winding at the side of R1 passing over the core and continuing counterclockwise. Imagine that the fingers of your left hand are wrapped around the core with the windings and in the direction of current flow. Your thumb would point in the direction of the magnetic north pole shown on figure 8-14. The second step is to determine the magnetic north pole of the load winding. The effect of the diode on the AC input must be considered before the LEFT-HAND THUMB RULE can be used as before. Since diode current flows from cathode to anode (Point C to D on figure 8-14), it is possible, by employing the rule, to identify the top of the load winding as the magnetic north pole.

8-37. After performing these first two steps, you can find out if the magnetic fields are aiding or opposing. Unlike poles will aid each other and cause the molecular magnets in the core material to align, the flux field to build up and the core to saturate faster. As indicated on figure 8-14, the poles at the top and bottom of the reactor are unlike. The resulting molecular magnet alignment causes saturation and an output pulse will be generated. On the other hand, when the fields are opposing each other the molecular magnets will align in two different directions. Without proper alignment flux cannot build up, the core cannot saturate and an output pulse cannot be obtained. These conditions are illustrated in figure 8-13. After determining if the magnetic fields in the reactor are aiding or opposing, the third step is to determine if there is a positive or negative output pulse. The output pulse polarity will be determined by the direction the diode allows current to flow through the load resistor. Current can be traced on figure 8-14 from ground, through the load resistor, diode and the reactor winding. The voltage drop across the load resistor will cause a positive potential at point C. This means that when current is flowing through the load resistor there will be a positive pulse at the output.

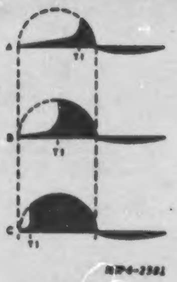


Figure 8-15. Effects of Control Current on Output Power

8-38. The fourth and final step is to determine the amount of pulse that will be present in the output. This is achieved by considering the position of the tap on the control resistor (R1) figure 8-14. With the tap in the position shown, maximum current will flow in the control winding. This causes maximum flux which allows early saturation and produces output waveform C of figure 8-15. When the control resistor tap is moved to point B there will be minimum current flowing through the control winding. The magnetic flux will be minimum, the reactor will take longer to go into saturation and waveform A of figure 8-13 will be the output. With the tap in the center position waveform B would be generated.

8-39. In the half-wave magnetic amplifier, DC power is delivered to the load for only a portion of one alternation of the input AC. If an alternating output is required, the magnetic amplifier of figure 8-16 can be employed. This circuit is called a full-wave magnetic amplifier because power is delivered to the output during both alternations of the input. The saturable reactor used in the full-wave amplifier is center tapped and the amplifier uses two diodes to ensure that current through the reactor load winding will always be in the same direction. As with the half-wave amplifier, changes of the control current will affect the amount of power delivered to the load as

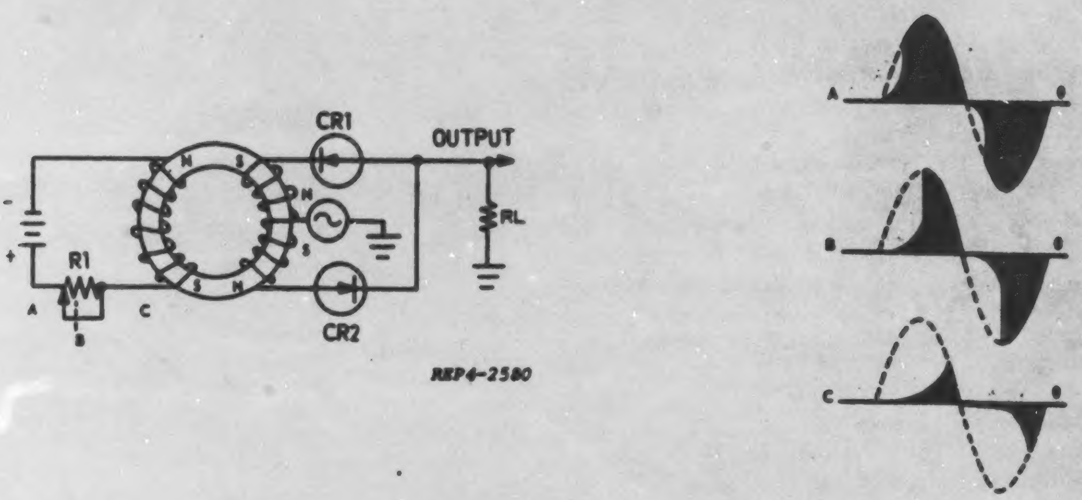


Figure 8-16. Full-Wave Magnetic Amplifier

shown by the waveforms of figure 8-16. With maximum control current (R1 at Point A), maximum load current will flow (waveform A). With R1 at point C, the waveform (C) shows that minimum power is delivered to the load.

8-40. Applying the LEFT-HAND THUMB RULE to the full wave saturable reactor, shows that the fields set up by the load winding will always be aiding the control flux regardless of the AC polarity. As a result, an output will be delivered to the load during each alternation of the AC power applied.

Chapter 9

SYNCHRO SYSTEMS

9-1. Applications of synchro systems are not new to you; the gas gauge on the dashboard in your car is one example. This chapter first explains the functions and uses of synchro systems; then it applies AC motor, generator, and transformer principles in explaining basic synchro operation.

9-2. Functions of Synchros

9-3. The function of a synchro system is to couple a mechanical position to an indicating device without mechanical linkage. This "mechanical position" is usually the position of a shaft and is called "angular position." A synchro is an inductive device capable of transforming an angular position input into an electrical output or an electrical input into an angular output.

9-4. Uses of Synchro Systems

9-5. Synchro systems are used in many types of electronic equipment. In typical radar equipment, the angular position of the antenna is shown on the indicator by the position of an illuminated line. The angular position of the illuminated line is synchronized with the antenna through use of the "synchro generator" and "synchro motor." Therefore, as the antenna rotates, the angular position of the illuminated line on the indicator changes in step with the antenna. The synchro generator and synchro motor with connecting lines are the basic synchro system.

9-6. A similar system is used in radio navigation equipment. Here, the position of a compass needle is synchronized with the antenna position through a synchro system.

9-7. In the examples given, the torque required is small. Therefore, a synchro system can be used. For applications where more torque is required than can be supplied by a synchro system, a different system will be required. This system is called a SERVOSYSTEM. A servosystem is used to turn an antenna.

9-8. Basic Principles of Synchros

9-9. The synchro generator and synchromotor are usually referred to as "synchros." Basic principles of synchros are the same as those of any motor and generator. The four most important principles are:

1. When a current is passed through a coil, the coil assumes the properties of a magnet.

2. The north and south poles of the magnetic field around a coil are determined by direction of current flow through the coil. That is, if the direction of current through a coil is reversed, the poles of its magnetic field will be reversed. The magnetic field may also be reversed by reversing the direction in which the coil is wound.

3. There is a force of attraction or repulsion between magnetic fields. Like poles repel, unlike poles attract.

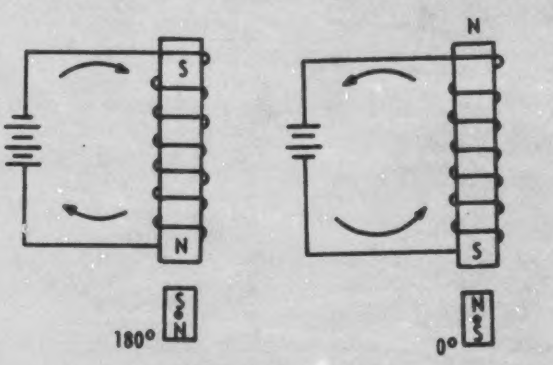


Figure 9-1

REP4-1353

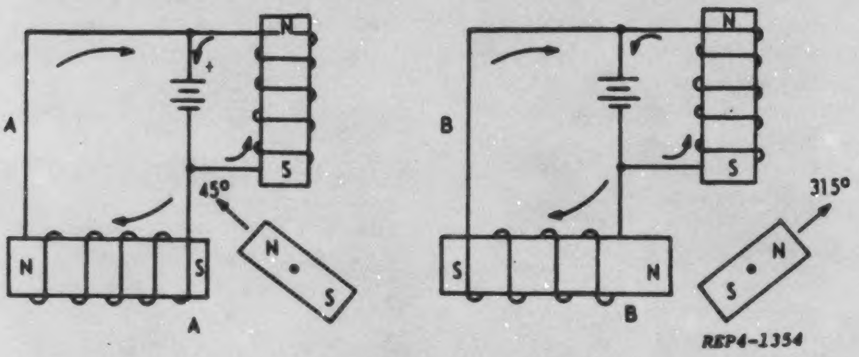


Figure 9-2

4. When there is RELATIVE MOTION between a conductor (coil) and a magnetic field, a voltage will be induced in the conductor (coil).

9-10. Positioning a Shaft with DC Voltages

9-11. Although the synchro is an AC device, DC voltages are sometimes used for positioning shafts. Since an understanding of shaft positioning with DC will help you analyze the operation of a synchro, it is well to take it up first.

9-12. Figure 9-1 shows a pivoted permanent magnet and a coil with a DC current flowing through it. There are two possible positions which the magnet can take since there are two possible magnetic fields. Notice that reversing the direction of current flow through the coil reverses the magnetic field of the coil and the position of the magnet.

9-13. In figure 9-2A we have placed two coils at right angles. The position which the rotating magnet takes is determined by the vector sum of the forces applied to it. If both coils have an equal magnetic-field strength, the pivoting magnet will take up an angular position of 45°. In figure 9-2B, we have reversed the direction of the magnetic field of one coil by reversing the direction in which it is wound. The rotor now takes up an angular position of 315°. In figure 9-2, there are four possible combinations of magnetic fields. Therefore, the rotating magnet has four possible positions which it can take: 45°, 135°, 225°, or 315°. The statements which we have made about figure 9-2 are only true if the magnetic field of both coils are equal. We have stated that the position of the rotating magnet is determined by the vector sum of the forces applied to it by the coils. Suppose that the magnetic field of one coil was made stronger than that of the other. In this case the rotating magnet would move TOWARD alignment with the coil of greatest magnetic field strength. It would NOT be in perfect alignment, however, unless the magnetic field of the other coil decreased to ZERO.

9-14. From the statements given above, you can see that two factors govern the position of the rotating magnet: direction of the magnetic fields of the coils, and relative strength of the magnetic fields of the coils. In figure 9-3 we have a circuit in which it is possible to vary both direction and relative strength of the two electromagnetic fields.

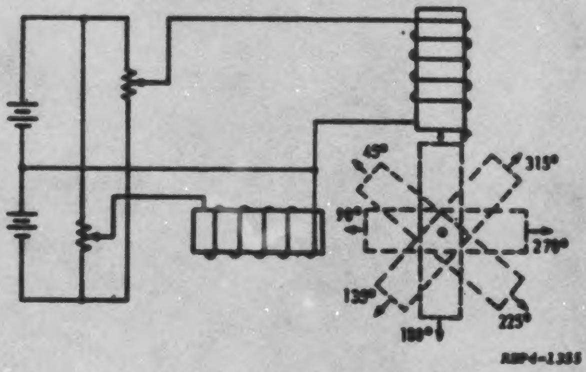


Figure 9-3.

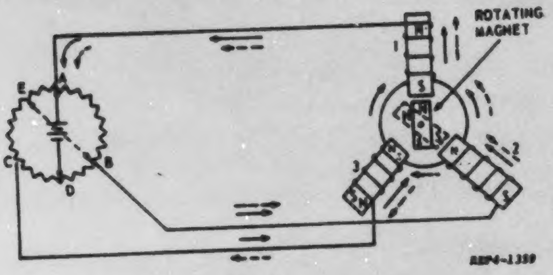


Figure 9-4

9-15. The rotating magnet in figure 9-3 can take ANY position in its 360° of rotation; therefore, it has an infinite number of possible positions. Figure 9-4 shows a practical DC remote indicating system. In this case the coils are arranged in what is called a "WYE" connection. Each coil has an angular position 120° removed from the other coils. Use of three coils allows a more positive control of the rotating magnet.

9-16. Notice that, in figure 9-4, when the potentiometer is moved CCW from point AD to point EB, that the rotating magnet moves CCW an equal number of degrees (60°). In the first position of the potentiometer (drawn in solid lines), Coil 1 has the greatest magnetic field strength because it has the largest current flowing through it. Coils 2 and 3 have an equal field, but their strength is less than that of Coil 1. Also notice the polarities of the magnetic fields of the three coils. Coils 2 and 3 are "pulling" on the south pole of the magnet, since Coils 2 and 3 have equal fields, the magnet will be positioned halfway between them (60° away from each). Coil 1 also holds the magnet in this position, since it "pulls" on the north pole of the magnet. When the potentiometer is moved (from point AD to point EB), the polarity of Coil 3 will be reversed. Therefore, Coils 1 and 3 will have the same polarity. The magnetic field strength of the coils will also change when the potentiometer is moved from point AD to point EB. At point EB, Coil 2 will have the greatest field strength; Coils 1 and 3 will have an equal field strength.

9-17. From these two cases you can see that all three coils in figure 9-4 exert a torque on the magnet. The amount of torque exerted by each coil is proportional to the strength of its magnetic field. The direction of the torque exerted by each coil is determined by current through the coil and the polarity of the magnet. The angular position which the magnet takes is determined by the vector sum of the torques applied by all three coils.

9-18. Synchro Construction

9-19. A synchro system requires a synchro generator and a synchro motor. Before going into the operation of the synchro generator and motor, let's first consider their construction. Both resemble small electric

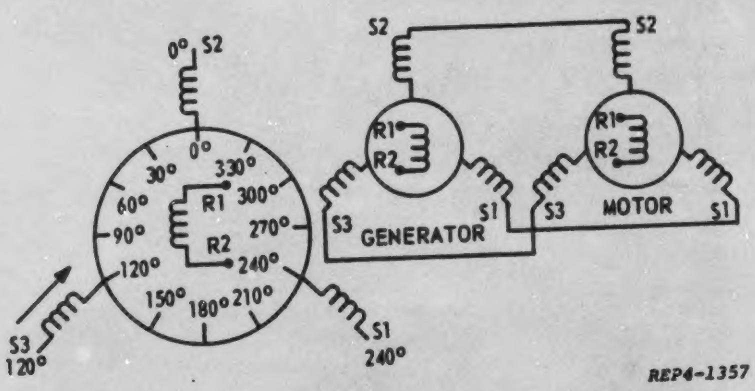


Figure 9-5

motors. Each consists of a fixed element called the stator and a movable element called the rotor. The stator consists of three coils placed in slots around the inside of a laminated-iron field structure and spaced 120° apart, very much like an ordinary 3-phase motor. Actually the groups overlap somewhat so the force which pulls the rotor into position is the same for all positions of the rotor. The 120° spacing of windings sometimes leads a person to believe that 3-phase voltage is used, but such is not the case. Only single-phase voltage is present.

9-20. The rotor consists of a coil of wire wound on a soft iron core and mounted on a shaft with the axis of the coil perpendicular to the shaft. Ball bearings reduce friction between the rotor shaft and its mount. The rotor is electrically connected to the external power source through two slip rings on the shaft.

9-21. The synchro motor and the synchro generator are essentially the same but a synchro motor tends to oscillate violently or spin continuously when the shaft is turned suddenly or when power is first applied to the system. To prevent this undesirable oscillation, the motor has a heavy metal flywheel, called an "inertial damper," mounted on one end of the shaft. This flywheel is mounted so that it turns freely on the shaft for approximately 45°, and then runs into a keyed bushing. This bushing which is fastened to the shaft through a friction disc also turns on the shaft but with a great deal of friction. For slow changes in position of the shaft, the flywheel follows along without much damping effect. But if the shaft tries to turn suddenly, the flywheel tends to stand still, and the friction disc acts as a brake which keeps the shaft from reaching a speed fast enough to start oscillation or spinning. If oscillation or spinning does occur, usually something is wrong with the damper.

9-22. Basic Synchros

9-23. Figure 9-5 shows the standard schematic diagram of a basic synchro system. Notice that stator coil leads are labeled S1, S2, and S3; rotor leads are labeled R1 and R2. Notice also that we divided the circle through which the rotor turns into degrees. We use these divisions of the circle to indicate the angular position of the rotor.

9-24. The synchro is an AC device. That is, it uses only AC as a source of power. Therefore, the magnetic fields present in the rotor and stator coils will alternate in polarity at the same rate as the AC source of power. For instance, we know that 60 Hz AC reverses direction of current flow 120 times per second and that the direction of current flowing through a coil determines the polarity of the magnetic field around the coil. Therefore, the polarity of the magnetic field around the coil will change 120 times per second.

9-25. Transformer Action in Synchros

9-26. An important factor in synchro operation is transformer action. In the synchro generator, AC voltage applied to the rotor winding is coupled to the stator windings through transformer action. The phase and amplitude of the voltage induced in each stator

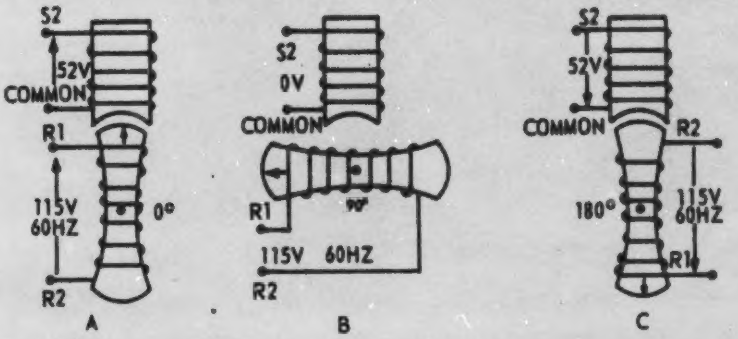


Figure 9-6

REP4-1358

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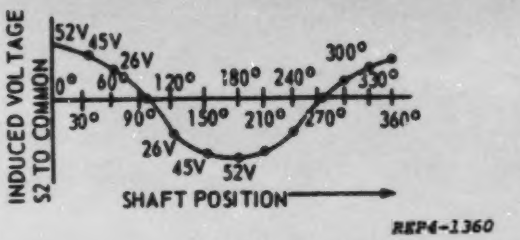
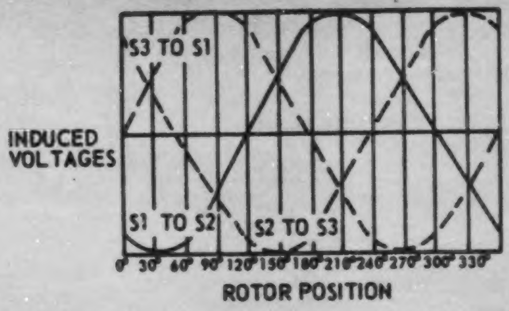


REP4-1360

Figure 9-7



REP4-1371

Figure 9-8

winding is determined by the angular position of the rotor. AC current through the rotor causes an electromagnetic field to expand and collapse at the AC rate, cutting the windings of the stator coils and inducing an AC voltage. This action takes place even though both stator and rotor are stationary. The amount of voltage induced in a stator winding depends on the angular relationship of the two coils. When two coils are parallel to each other, coupling between the two coils will be maximum. When two coils are at right angles to each other (90°) coupling will be zero. Figure 9-6 indicates the effect of angular relationship on coupling. Observe that the rotor windng has 115 V, 60 Hz applied. It is the magnetic field of the rotor that induces 52 V in S2 in figure 9-6A and C. In the perpendicular position, (figure 9-6B) induced voltage is zero.

9-27. In a synchro, as the rotor is turned through a full circle (360°) the voltage induced in each stator will vary as shown in figure 9-7. The graph shows the amplitude and phase of the induced voltage for one stator winding. Values plotted above zero indicate an in-phase condition between rotor and stator while values plotted below zero indicate an 180° out-of-phase condition. The shape of the curve is that of a sine wave whose frequency is determined by the time it takes the rotor to turn through 360°. Since all three stators lie in different directions, no two stators will have the same curve. Figure 9-8 shows the relative amplitude and phase of the voltages induced between points S1, S2, and S3 for various positions of the rotor. Note that each stator reaches a maximum induced voltage twice in a 360° rotation of the rotor. Also, notice that the reference line represents the point at which the phase changes as well as the point of zero induced voltage. This change of phase in the stators, with respect to the phase of current in the rotor, is illustrated in figure 9-9A and B.

9-28. In standard synchros, the maximum voltage induced in each stator coil is 52 volts RMS when 115 volts RMS is applied to the rotor. The maximum voltage across a pair of stators is 70 volts RMS.

9-29. We have seen how the angular position of the synchro rotor can control the amplitude and phase of the voltage induced

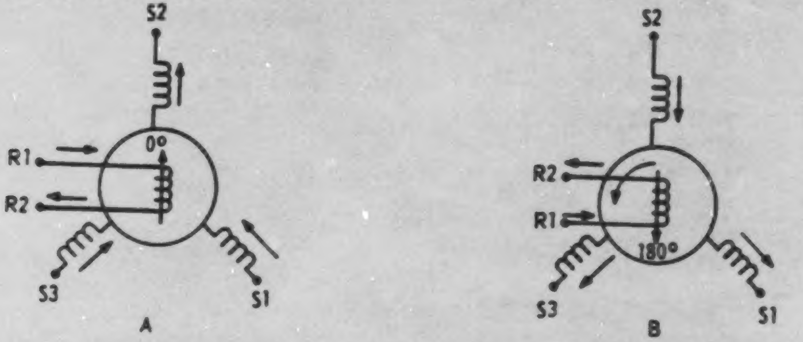


Figure 9-9

REP4-1372

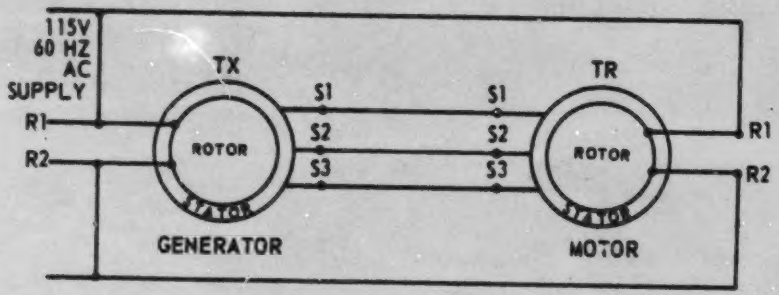


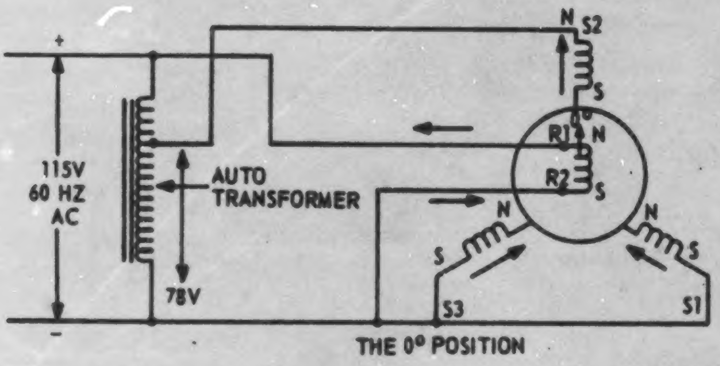
Figure 9-10

in the stator windings. In other words, we have changed the angular position information of the rotor into electrical information in the stators. This is the action which takes place in a synchro generator (refer to figure 9-10). The output of the synchro generator is coupled to the synchro motor. In the synchro motor, the electrical information is used to control the angular position of the rotor. Figure 9-10 shows the connections between synchro generator and synchro motor. Let us see how the inputs to the synchro motor control the position of its rotor.

9-30. Synchro Motors

9-31. Figure 9-11 shows a basic synchro motor. The autotransformer input to the motor simulates the output from a synchro generator whose rotor is positioned at 0°. The arrows indicate the direction of current flow in rotor and stators for the positive half-cycle of applied voltage. Note that stators S1 and S3 are in parallel, therefore, they will have magnetic fields of equal strength and polarity. Stator S2 has the greatest magnetic field strength since all current that flows through S1 and S3 must flow through S2. The polarities of the magnetic fields will lock the rotor in the position shown. On the negative half-cycle, all currents in the synchro will be reversed and, therefore, the polarity of the stator and rotor magnetic fields will be reversed. The rotor will still be locked in the position shown. The net torque on the rotor will be zero.

9-32. In figure 9-12 the phase of current in the stator windings has been reversed from that of figure 9-11 by switching leads from the autotransformer to the stators. Notice that the rotor has moved to the 180° position



REP4-1356

Figure 9-11

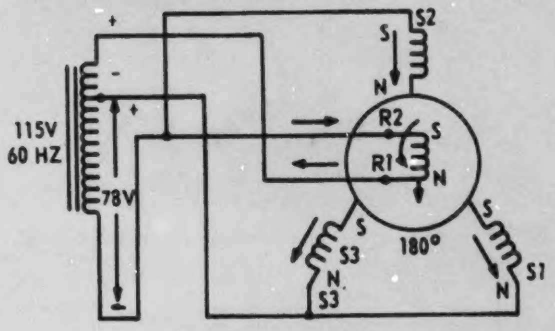
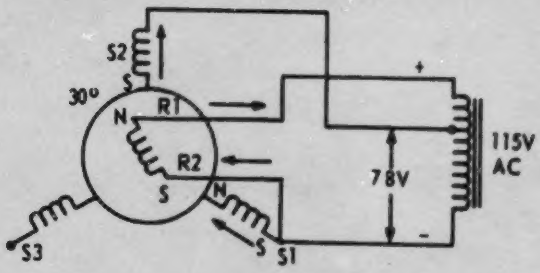

+
-
+
115V
60 HZ
78V
S2
S
N
R2
S
R1
N
S
S3
180°
S
S1
N
N
S3

Figure 9-12

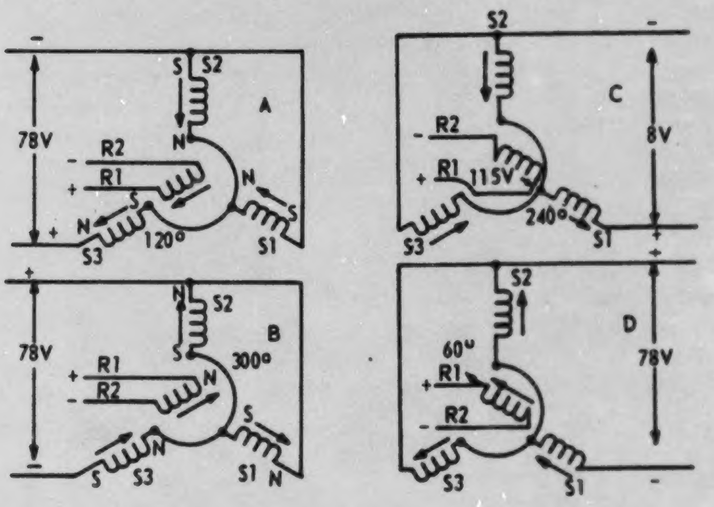

S2
S
30°
N
R1
R2
S
N
S3
S
S1
+
78V
115V
AC
-

REP4-1350

Figure 9-13

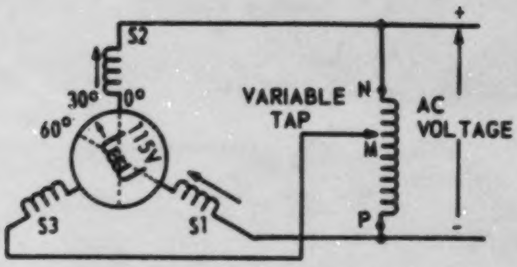
in order to align the stator and rotor magnetic fields. Two positions of the rotor can thus be obtained by changing the phase of the current in the three stator windings with respect to the phase of current in the rotor winding. To position the rotor anywhere other than 0° and 180°, it is necessary to vary either the relative amplitude or phase of current in the individual stators. In figure 9-13, we have varied the amplitude of the current in stator S3 by disconnecting it. The rotor now aligns with the magnetic field that exists between stators S2 and S1.

9-33. Figure 9-14 shows the effect of varying both phase and amplitude in the stators. In A and C the rotor position has been changed by switching leads to the stators which in turn changed the relative amplitudes of current in the stators windings.


A
B
C
D
78V
S2
R2
R1
N
S
S1
S3
120°
300°
8V
115V
240°
60°

REP4-1351

Figure 9-14



REP4-1352

Figure 9-15

9-34. In figure 9-15, amplitude and phase of current is varied in one stator (S3) while stators S2 and S1 are held constant. Positioning the variable tap on the autotransformer will control the position of the rotor over a 60° arc. When the variable tap is at position N, the rotor will be at the 60° position, at M the rotor will be at the 30° position, at P the rotor will be at the 0° position. Notice that, at position M, the current in S3 is zero. Current through S3 will decrease as the variable tap is moved from position N toward position M, reverse phase as it passes through position M, and increase as it moves toward position P.

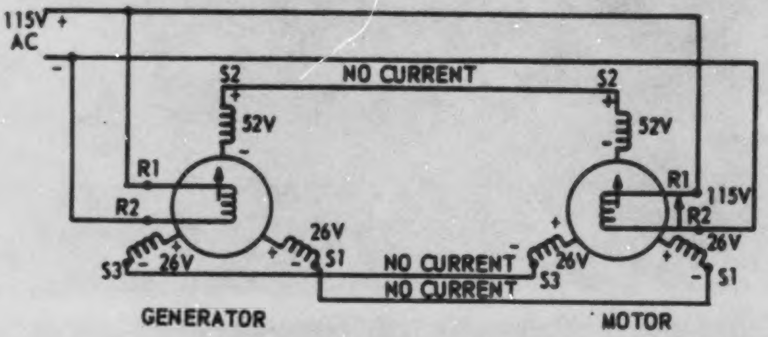
9-35. Synchro Motor and Generator Connections

9-36. When a generator and motor are properly connected, you have a complete synchro system in which the motor shaft follows the generator shaft. The proper connections for a synchro system are shown in figure 9-16. Note that the rotors are connected so that both R1 terminals are connected to the same side of the supply line and both R2 terminals to the other. In this way, the two rotors have voltages applied which are identical in magnitude, phase, and frequency.

9-37. Each motor lead is connected to its corresponding generator lead. Each stator winding of the motor has a voltage induced in it which is opposed by an equal voltage in the corresponding stator winding of the generator. Thus, no current will flow in the stator windings of either motor or generator. The conditions shown in figure 9-16 exist when motor and generator rotors are at the 0° position. When the rotor positions are changed, the voltages induced in the stators will change. However, if both motor and generator are in corresponding positions, no current will flow in the stators and no torque will be produced.

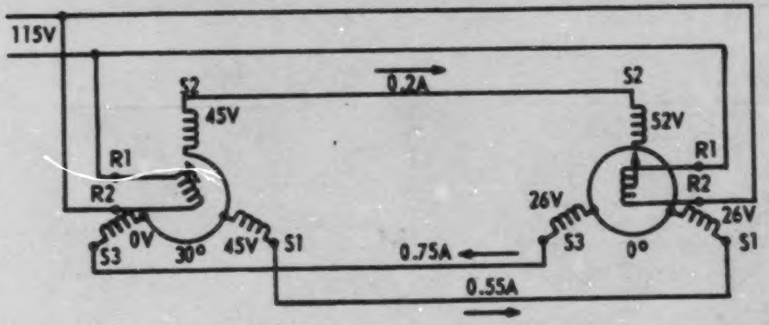
9-38. When the rotors are not in corresponding positions, the voltage induced in corresponding stators will NOT be equal and current will flow in the stator windings of both motor and generator. This is illustrated in figure 9-17. The current flowing in the stators will cause a magnetic field which will interact with the magnetic field around the rotors and cause a torque to be exerted on the rotors of both motor and generator. This is illustrated in figure 9-18. Notice that the torque is in opposite directions in motor and generator. Both torques try to turn the rotors toward corresponding positions.

9-39. In a normal synchro system, the generator rotor will be positioned by an external device. Therefore, only the motor rotor will



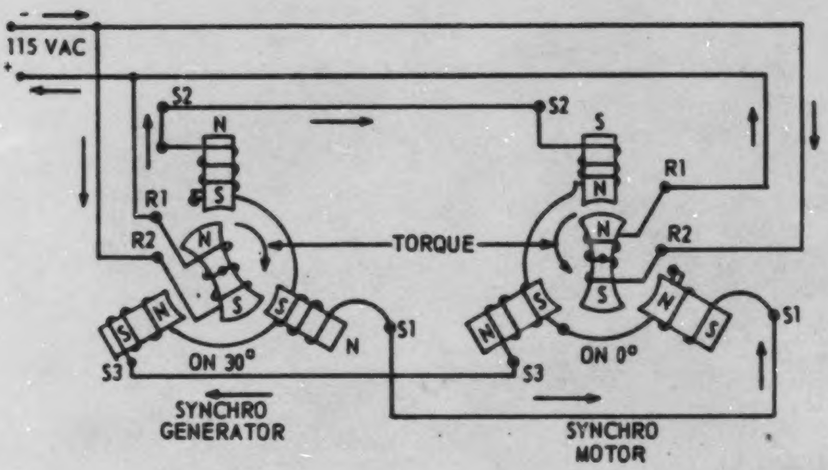
REP4-1361

Figure 9-16


115V
S2
45V
0.2A
S2
52V
R1
R2
R1
R2
26V
26V
S3
0V
30°
45V
S1
0.75A
S3
0°
S1
0.55A

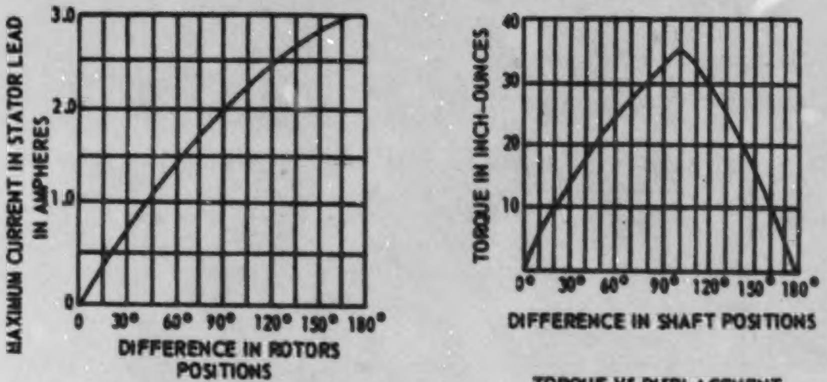
REP4-1362

Figure 9-17


-
115 VAC
+
S2
N
S
S2
S
N
R1
R2
N
S
TORQUE
R1
R2
N
S
S
N
N
S
N
S
ON 30°
S1
S3
ON 0°
S1
S3
SYNCHRO GENERATOR
SYNCHRO MOTOR

REP4-1368

Figure 9-18



STATOR CURRENT VS DIFFERENCE IN ROTOR POSITIONS "A"

TORQUE VS DISPLACEMENT "B"

REP4-1369

Figure 9-19

be free to turn toward a position of correspondence. Stator current is almost directly proportional to the difference in rotor positions. Maximum torque is exerted at approximately 105°. This is illustrated in figure 9-19A and B.

9-40. Under normal operating conditions, the motor rotor will follow the generator rotor so that the difference in rotor positions is small.

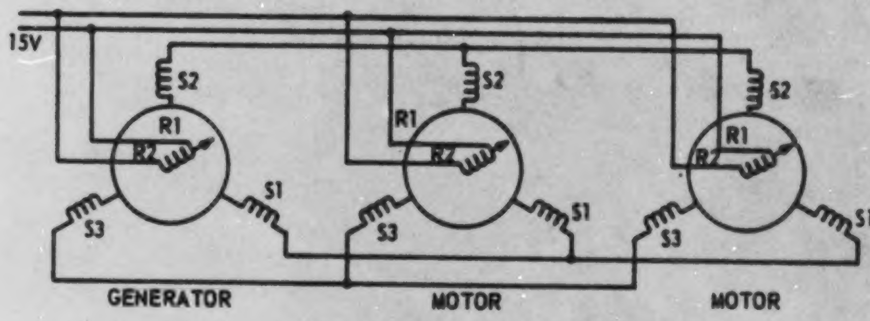
9-41. One synchro generator is sometimes used to position several synchro motors. The standard type of connection is shown in figure 9-20.

9-42. In such a system the generator power must be adequate to maintain a high degree of accuracy. If too many motors are connected, output voltages of the generator are reduced and excessive lag occurs in all the motors. If any one motor turns hard or becomes jammed, the accuracy of the whole system is decreased.

9-43. Servoamplifier

9-44. Most low power servomechanisms employ a two-phase induction motor to turn a remote indication device. A servoamplifier is used to obtain enough power to operate the servomotor in the correct direction and at proper speed. To analyze the relationship of the servoamplifier to a synchro system refer to figure 9-21.

9-45. An input shaft mechanically drives the rotor of a synchro generator. The stator windings of the synchro generator are connected to the stator windings of the control transformer. A control transformer is a type of synchro which has both an electrical and a mechanical input and an electrical



REP4-1370

Figure 9-20

142

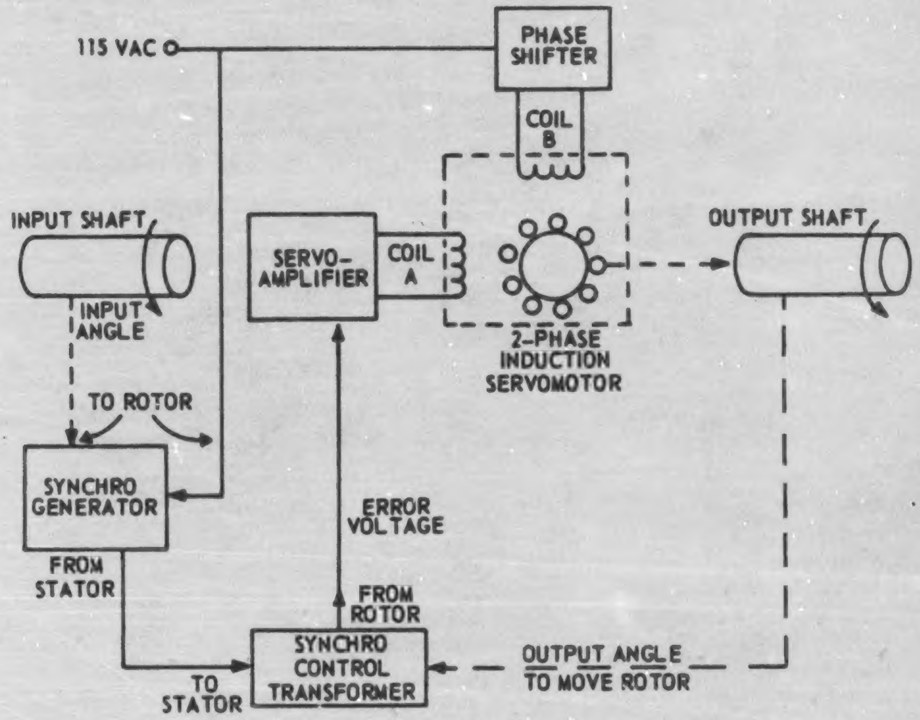

115 VAC
PHASE SHIFTER
COIL B
INPUT SHAFT
INPUT ANGLE
SERVO-AMPLIFIER
COIL A
OUTPUT SHAFT
2-PHASE INDUCTION SERVOMOTOR
TO ROTOR
SYNCHRO GENERATOR
ERROR VOLTAGE
FROM STATOR
FROM ROTOR
SYNCHRO CONTROL TRANSFORMER
OUTPUT ANGLE TO MOVE ROTOR
TO STATOR

Figure 9-21. Servomechanism with AC Servo Motor

REP4-1374

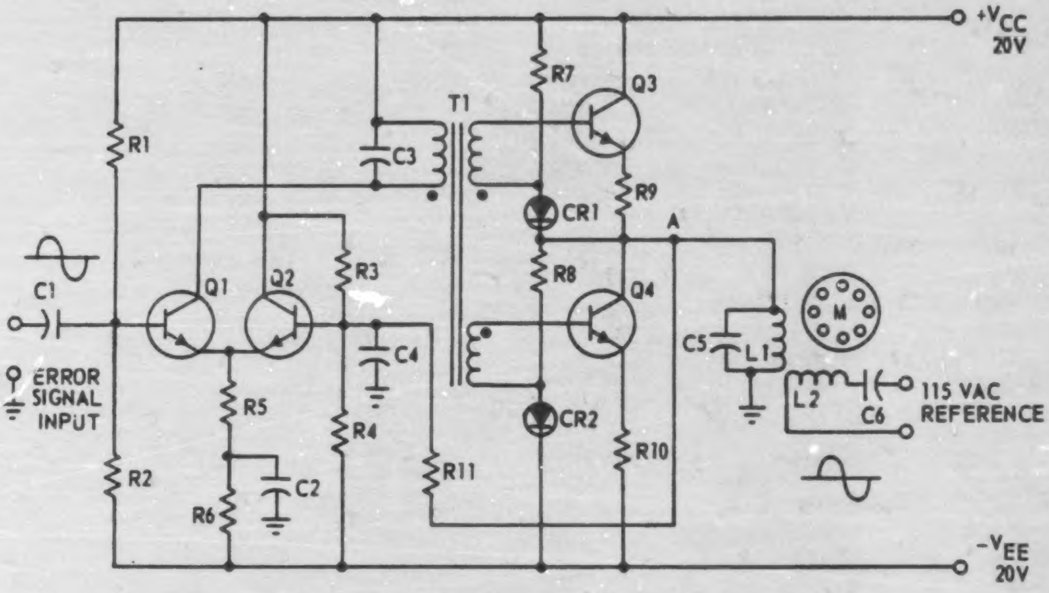

+VCC 20V
R7
Q3
T1
R1
C3
R9
CR1
A
Q1
Q2
R3
R8
Q4
C1
C4
C5
L1
M
ERROR SIGNAL INPUT
R5
R4
CR2
L2
C6
115 VAC REFERENCE
R11
R10
R2
C2
R6
-VEE 20V

Figure 9-22. Servo Amplifier

REP4-1373

output. The output from the rotor of the control transformer is an "error voltage." If the rotor of the control transformer is aligned with the rotor of the synchro generator, then the error voltage will be zero volts. Therefore, the amplitude of the error voltage will be determined by the angular difference between the input shaft and the rotor of the control transformer. The phase of the error voltage will indicate the direction of rotation required to correct the error.

9-46. The error voltage from the rotor of the control transformer is applied to the servoamplifier. The servoamplifier amplifies this voltage without shifting its phase. The load for the servoamplifier is field coil A of the 2-phase induction servomotor. Field coil B of the servomotor is energized at all times by the 115VAC reference voltage fed to the phase shifter. The amplitude of the voltage applied to coil A will determine the speed of rotation of the servomotor. The phase of the voltage will determine the direction of rotation.

9-47. The servomotor mechanically drives the output shaft which is mechanically coupled to the rotor of the control transformer. When the rotors of the synchro generator and control transformer are at the same angle, the error voltage will return to zero. With no input to the servoamplifier, the servomotor will stop turning the output shaft. When this condition exists, the system is aligned. Figure 9-22 illustrates a transistorized servoamplifier circuit. In this particualr system, the two-phase induction motor (M) is the servomotor. The speed and direction of the motor rotation vary as the phase and magnitude of the error signal input changes. The error voltage is amplified by transistors Q1, Q3 and Q4 and is applied to the control winding (L1) of the servomotor (M). Coil L2 of the servomotor is connected to the 115-VAC input reference through capacitor C6 to obtain a 90° phase difference between the voltages applied to the reference (L2) and control (L1) windings in the servomotor. If there is no error voltage, the motor remains stationary since only one phase of the voltage is being applied to the motor and no rotating magnetic field exists. If there is an error voltage, it is an AC voltage which is either in phase or out of phase with the voltage applied to the synchro generator. Thus, the voltage applied to control winding L1 either leads or lags the voltage applied to reference winding L2 by 90°. This condition sets up a rotating magnetic field which causes the motor to turn in the proper direction to null the error voltage.

9-48. A servoamplifier consists essentially of two stages: an error amplifier (preamplifier) and a power amplifier. Let's look at the power output stage first.

9-49. Transistors Q3 and Q4 are forward biased from the voltage divider network consisting of CR2, R8, CR1, and R7. This network is connected across the voltage source $-V_{EE}$ to $+V_{CC}$. If the two voltage sources are equal ($-V_{EE} = 20V$ and $+V_{CC} = +20V$) and R8 = R7, the voltage at point A will be zero volts with respect to ground. The forward bias on Q3 is equal to the voltage across CR1. The forward bias on Q4 is equal to the voltage across CR2. CR1 and CR2 are used for temperature stability. Resistors R9 and R10 are small emitter resistors that also provide temperature stability. Under these conditions each transistor is conducting a small amount. The current path is as follows: From $-V_{EE}$ through R10, Q4, R9, Q3, to $+V_{CC}$. There is no current through L1 at this time.

9-50. Transformer T1 is connected so the signal applied to the base of each transistor is equal in amplitude but 180° out of phase. Note the dots on the transformer. As one transistor conducts more, the other conducts less.

9-51. Assume Q3 is forward biased and Q4 is cut off. Current flows from ground through L1- R9, and Q3 to $+V_{CC}$. Conversely, when Q4 is forward biased and Q3 is cut off, current flows from $-V_{EE}$ through R10, Q4, and L1 to ground. This arrangement develops an AC signal across L1. You can recognize this circuit as a push-pull amplifier.

9-52. The error amplifier consists of Q1, Q2, and associated components. Resistors

R1 and R2 provide forward bias for Q1. Resistors R3 and R4 provide forward bias for Q2. R6 is for temperature stabilization. C2 prevents degeneration across R6, R5 is used to provide coupling between Q2 and Q1.

9-53. The circuit composed of Q1 and Q2 is called a "differential amplifier." "Differential" pertains to or involves a difference. A differential amplifier has two inputs and responds to the difference between them. When the two inputs are alike (phase and amplitude), there is no output from the circuit.

9-54. One input to the differential amplifier is the error signal that is applied to the base of Q1. The other input signal, taken from control winding L1 (point A), is applied to the base of Q2. To explain the operation, we will first consider the circuit when the rotor of the control transformer is aligned with the rotor of the synchro generator (no error voltage).

9-55. With no error signal generated, neither Q1 nor Q2 will have a signal input, therefore, the difference will be zero. Since Q1 and Q2 are both forward biased, they will be conducting the emitter current of each transistor flow through R5 and R6. The voltage on the emitter is dependent on the conduction of Q1 and Q2. A change in conduction of either transistor will affect the other (emitter-coupled).

9-56. Now, suppose the synchro generator rotor is turned so it is no longer aligned with the control transformer rotor. An error signal is generated which is applied to the base of Q1. If the input signal is positive, Q1 will conduct harder and develop a negative going signal on its collector. Observing the phasing dots on T1, the positive alternation of the signal is applied to the base of Q3 which will conduct harder. As Q3 conducts harder, current will flow from ground through L1 developing a positive voltage at point A. The servomotor starts turning. The voltage at point A is fed back to the base of Q2 through R11 and across C4. R11 and C4 are called "feedback" components. The signal on the base of Q2 is smaller than at point A and it is delayed by the action of R11 and C4. From the base of Q2, the signal is coupled to the emitter of Q1. At this time Q1 has two input signals; one is the error signal and the other is the delayed signal from point A. The output of Q1 will be the difference between these two signals.

9-57. When the input signal is on its negative alternation, Q1 will conduct less and develop a positive signal on its collector. This signal feeds through T1 to cause Q4 to conduct harder. The current flows from $-V_{EE}$ through R10, Q4 and L1 to ground. The positive and negative alternations of the error signal input cause Q3 and Q4 to conduct alternately. Q3 and Q4 form the push-pull amplifier, which provides the alternating current required by L1 to rotate the motor.

9-58. The amplitude of the error signal input determines the amount of current through L1. This determines the speed of the motor. The phase of the input signal determines the phase of L1 current. If this current leads the current through L2, the motor rotates in one direction; if it lags, the motor rotates in the reverse direction.

9-59. When the control transformer rotor approaches alignment with the synchro generator rotor, the error signal becomes smaller. As soon as the control transformer rotor is exactly aligned with the synchro generator rotor, the error signal is zero. At this time the circuit is in its original stable condition.

9-60. The signal that is applied to the base of Q2 is needed to fix amplifier gain and reduce output impedance. The gain of a servoamplifier should be the same for starting the motor as for running it. The signal applied to the base of Q2 ensures that the gain remains constant for these conditions. This feedback signal also lowers the output impedance of Q3-Q4 so that it matches the low impedance of L1.

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NOTES

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Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 34

SOLID STATE POWER SUPPLY RECTIFIERS AND FILTERS

1 September 1975

AIR TRAINING COMMAND

7-9

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ELECTRONIC PRINCIPLES

MODULE 34

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

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OVERVIEW

1. SCOPE: Solid state power supply rectifiers change AC to pulsating DC, which is then filtered. The resulting DC voltages are used for transistor operation and other requirements in electronic equipment. In general, there are three types of rectifiers. These are the half-wave, full-wave, and bridge rectifier. This chapter discusses these three types plus a three-phase full-wave rectifier.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives:

a. Given the schematic diagram for an unfiltered semiconductor half-wave rectifier, effective AC input voltage, input frequency, and a list of statements, select the statement that describes and/or identifies the

(1) current path.
(2) output ripple frequency.
(3) peak output voltage.
(4) output waveform.

b. Given the schematic diagram for an unfiltered semiconductor full-wave rectifier, effective AC input voltage, input frequency, and a list of statements, select the statement that describes an/or identifies the

(1) current paths.
(2) output ripple frequency.
(3) peak output voltage.
(4) output waveform.

c. Given the schematic diagram for an unfiltered semiconductor bridge rectifier, effective AC input voltage, input frequency, and a list of statements, select the statement that describes and/or identifies the

(1) current paths.
(2) output ripple frequency.
(3) peak output voltage.
(4) output waveform.

d. Given the schematic diagram for an unfiltered semiconductor three-phase rectifier (full-wave), effective AC input voltage, input frequency and a list of statements, select the statement that describes and/or identifies the

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(1) current paths.
(2) output ripple frequency.
(3) peak output voltage.
(4) output waveform.

e. Given a list of statements, select the one that describes the effect of filtering on half or full-wave rectification.

f. Given a schematic diagram of a semiconductor voltage doubler and the effective AC voltage, determine the peak output voltage.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text V

AUDIO-VISUALS:

Television Lesson 30-301A, Filters and Power Supplies
Television Lesson 30-307, Voltage Doubler
Television Lesson 30-236, Bridge Rectifiers

LABORATORY EXERCISE:

Laboratory Exercise 34-1, Solid State Power Supply Rectifiers and Filters.

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced material as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

All electronic equipment requires power to operate regardless of its function or size. The power source is usually referred to as the power supply section or unit, and although there are many different types and sizes, they all function generally the same.

The primary function of the power supplies you are about to study is to provide direct current and voltage to other electronic circuits for their operation. This is accomplished by converting alternating current (AC) to direct current (DC) by means of rectification, filtration, and in many cases regulation.

The importance of power supplies should be obvious. Without the correct voltage and current levels available to the circuits, equipment could not function.

The first chapter of your text covers voltage rectification by various types of rectifiers. You should study the text material carefully and be able to explain the operation of each type.

A. Turn to the Student Text, Volume V, and read paragraphs 1-1 through 1-20. Return to this page and answer the following questions.

1. By definition, a rectifier is a device which changes ____________________ to ____________________.

2. An ideal rectifier is one that offers ____________________ impedance to the flow of current in one direction and an ____________ impedance to the flow of current in the opposite direction.

3. True or False. A simple half-wave rectifier consists of a source of AC power, a diode and a load resistor.

4. A rectifier circuit with a "Large Load" implies that R_L is (large/small), and the circuit current is (high/low).

5. True or False. In a half-wave rectifier, current flows during both halves of the input wave.

6. In a half-wave rectifier circuit, what is the peak output voltage equal to?

7. Calculate the peak output voltage for the circuit shown in figure 34-1.

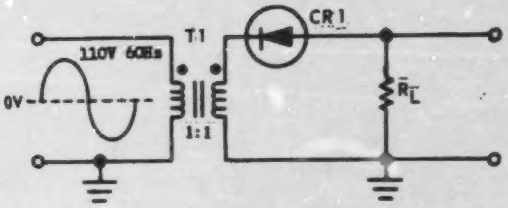


Figure 34-1. Half-Wave Rectifier

8. The peak inverse voltage across the diode in a half-wave rectifier is equal to ____________________.

9. If you were selecting a diode for a circuit which has a peak inverse voltage of 282.8 volts, what must the minimum breakdown voltage rating for the diode be?

10. In a half-wave rectifier circuit, how many output pulses will be generated for each cycle of the applied AC signal?

11. True or False. The output ripple frequency of a half-wave rectifier will be equal to the frequency of the applied AC signal.

12. Trace the current path through the circuit in figure 34-1 for the negative alternation of the AC input.

13. Draw the output voltage waveform with voltage levels for the circuit in figure 34-1.

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

B. Turn to Student Text, Volume V, and read paragraphs 1-21 through 1-27. Return to this page and answer the following questions.

1. True or False. A full-wave rectifier permits current to flow in the same direction through the load resistor during both alternations of the AC input.

2. What difference exists in the transformer secondary of a full-wave rectifier from that of a half-wave rectifier?

____

____

3. True or False. Both diodes conduct at the same time in a full-wave rectifier.

4. How can the output polarity of a full-wave rectifier be changed?

5. What is the ripple frequency of a full-wave rectifier if the input frequency is 60 hertz?

6. What is the ratio of ripple frequency output to signal frequency input in a full-wave rectifier?

7. What is the peak inverse voltage of a full-wave rectifier with a peak output voltage of 200 volts?

8. What is the average output voltage from a full-wave rectifier if the peak output is 200 volts?

9. What is the advantage of a full-wave rectifier over a half-wave rectifier with the same peak output voltage?

10. Calculate the peak output voltage for the circuit in figure 34-2.

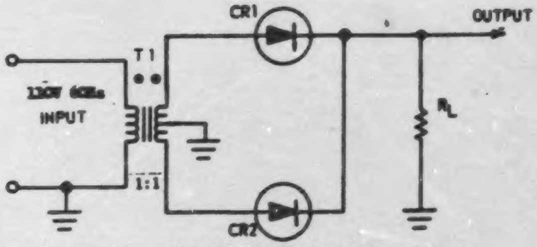


Figure 34-2. Full-Wave Rectifier

11. Trace the current paths through the circuit in figure 34-2 for both alternations of the AC input.

12. Draw the output waveform for the circuit in figure 34-2.

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

C. Turn to Student Text, Volume V, and read paragraphs 1-28 through 1-34. Return to this page and answer the following questions.

1. How does the transformer secondary for a bridge rectifier differ from that of a full-wave rectifier?

2. How many diodes are required for a bridge rectifier?

3. True or False. In a bridge rectifier, current will flow through two diodes during each half of the input signal.

4. What is the output ripple frequency of a bridge rectifier with a 60 hertz input signal frequency?

5. The peak inverse voltage of a bridge rectifier with a 200 volt peak output is

6. True or False. Peak inverse voltage for a half-wave, full-wave, and bridge rectifier is the peak voltage applied across the entire secondary of the input transformer.

7. True or False. To change the output polarity of a bridge rectifier, it would be necessary to reverse only one pair of diodes.

8. Calculate the peak output voltage for the circuit in figure 34-3.

9. Trace the current path through the circuit in figure 34-3 for both alternations of the AC input.

10. Draw the output waveform with voltage levels for the circuit in figure 34-2.

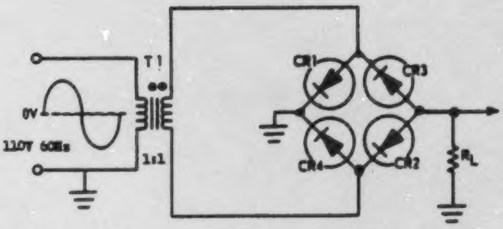


Figure 34-3. Full-Wave Bridge Rectifier

CONFIRM YOUR ANSWERS AT THE BACK OF THE BOOK.

D. Turn to Student Text, VolumeV, and read paragraphs 1-35 through 1-43. Return to this page and answer the following questions.

1. What is the phase angle between each of the three inputs to a three-pahse rectifier?

2. Assuming equal number of turns in the transformer, a delta-wound primary with a wye-wound secondary steps up the

3. With equal windings, a wye primary with a delta secondary steps up the

4. The ripple frequency output of a three-phase rectifier with a 60 hertz input is

5. True or False. To change the output polarity of a three-phase rectifier, it is necessary to reverse each diode.

6. By comparison to single phase rectifiers, the ripple amplitude in the output voltage of a three phase rectifier is

7. Calculate the peak output voltage for the circuit in figure 34-4.

8. Trace the current path through the circuit in figure 34-4 when terminal "B" is positive (+) and terminal "C" is negative (-).

9. Draw the output waveform for all three phases of the rectifier shown in figure 34-4. Label the minimum and maximum (peak) voltages.

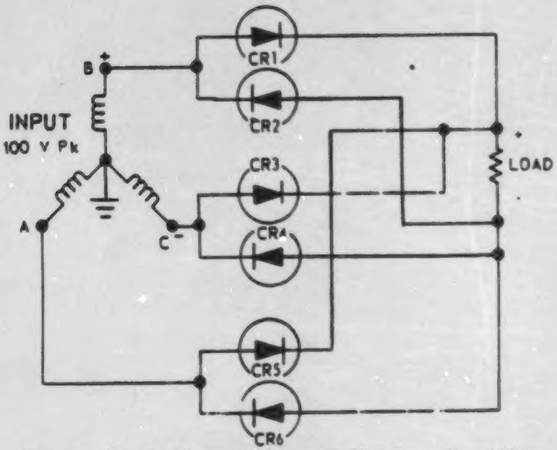


Figure 34-4. Three-Phase Full-Wave Rectifier

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

E. Turn to Student Text, Volume V, and read paragraphs 1-44 through 2-18. Return to this page and answer the following questions.

1. The primary purpose of power supply filters is to convert ______________ to ______________.

2. How does a filter affect the amplitude of the ripple voltage in the output of a rectifier?

____

3. The ideal capacitive filter would have a ______________ charge time and a ______________ discharge time.

4. True or False. Simple capacitive filters are not sufficient for rectifiers that must supply a large load current.

5. True or False. Inductive filters used in rectifier circuits are placed in series with the load.

6. True or False. The advantage of a capacitive input filter compared to an inductive input filter is that the capacitor can charge faster to a higher voltage.

7. When compared to capacitive input filters, inductive input filters give a (higher/lower) output voltage and (good/fair) voltage regulation.

8. Capacitive input (LC) filters give (higher/lower) output voltage but (less/more) voltage regulation, when compared to inductive input filters.

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

F. Turn to Student Text, Volume V, and read paragraphs 2-19 through 2-24. Return to this page and answer the following questions.

1. Comparing LC and RC Pi filters, the ______________ Pi filter yields the highest output voltage and best voltage regulation.

2. Name the three components of an LC Pi-Type filter.

3. True or False. Pi-Type filters are always capacitive input filters.

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

G. Turn to Student Text, Volume V, and read paragraphs 2-25 through 2-33. Return to this page and answer the following questions.

1. True or False. A voltage doubler converts AC to DC.

2. The output voltage of a voltage doubler with a peak secondary voltage of 100 volts is

____

3. The output ripple frequency of a voltage doubler with a 60 Hz input will be

____

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

H. Turn to laboratory exercise 34-1 and complete all sections. You will notice that the exercise is arranged in the same logical sequence as the material in the student text. Now you will be able to put into practice what you learned in theory by actually performing and observing the results in the actual circuit. Keep in mind that this is the most important part of your training for the end result is measured by how well you can work on the actual circuits.

UPON COMPLETION OF LABORATORY EXERCISE 34-1, YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 34-1

OBJECTIVES:

1. Given a Rectifier/ Filter trainer, schematic diagram, oscilloscope, and multimeter, measure the output ripple amplitude and frequency of an unfiltered half-wave and full-wave ractifier.

2. Given a Rectifier/Filter trainer, schematic diagram, oscilloscope, and multimeter, measure the output voltage and ripple amplitude of a filtered half-wave and full-wave rectifier.

EQUIPMENT:

1. LC-RC Filtering Characteristics, Trainer #4865.
2. Oscilloscope with 10:1 attenuator probe.
3. Multimeter.

REFERENCES:

Student Text, Volume V, Chapters 1 and 2.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Analysis of the trainer

a. The trainer incorporates switching arrangements and a rheostat for:

(1) Changing from half-wave to full-wave rectification (S102).
(2) Selection of different filter combinations (S103, S104, S105).
(3) Varying load resistance (R104).

2. Preparation of the equipment:

a. OSCILLOSCOPE CONTROLS

	OSCILLOSCOPE CONTROLS	POSITION
(1)	POWER	ON
(2)	VERTICAL MODE	"A"
(3)	VOLTS/DIV	5 Calibrated
(4)	POLARITY	Normal AC
(5)	TRIGGER SELECTOR	Line +
(6)	MODE	Auto
(7)	HORIZONTAL DISPLAY	Normal
(8)	TIME/DIV	5 milliseconds, calibrated
(9)	FOCUS and INTENSITY	Well Defined Sweep

b. Trainer to the Oscilloscope:

(1) Ground oscilloscope to trainer at TP111.

(2) Connect Channel A probe to TP108 10:1 attenuator probe.

c. MULTIMETER CONTROLS

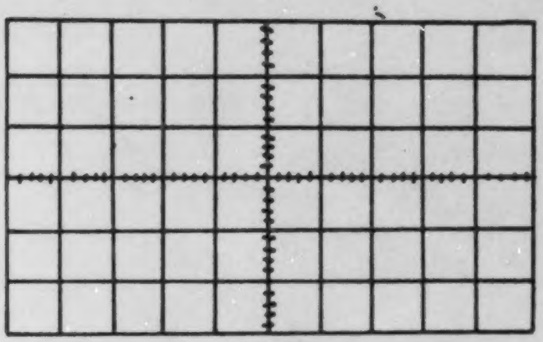
	MULTIMETER CONTROLS	POSITION
(1)	FUNCTION	20 k ohm/volt
(2)	RANGE	250 volt
(3)	NEGATIVE LEAD	Trainer ground TP107
(4)	POSITIVE LEAD	Trainer TP106

d. TRAINER CONTROLS

	TRAINER CONTROLS	POSITION
(1)	S101	OFF
(2)	S102	HW (RIGHT)
(3)	S103	0 (CENTER)
(4)	S104	SHORT (CENTER)
(5)	S105	0 (CENTER)
(6)	R104	FULLY CLOCKWISE

3. Activity

a. With the trainer set up to function as a half-wave unfiltered rectifier, and 140 V AC, 60 hertz, input to the rectifiers, calculate and draw 3 cycles of the output waveform on Graph #1 showing the output voltage, ripple amplitude, and frequency that should appear at TP108. (Use formulas to determine the waveshape amplitude.)



GRAPH #1

b. Turn S101 to the ON position.

c. Measure and record the output.

(1) Multimeter ____________ V_{av}

(2) Oscilloscope ____________ V_{pk}

(3) Number of positive pulses ________

NOTE:

(1) The oscilloscope probe attenuates the signal by a factor of 10. To calculate the actual output voltage, multiply by 10.

(2) Formulas to assist you during the laboratory exercise:

Peak Voltage = $E_{effective}$ X 1.414

Average Voltage = E_{peak} X .318 (For H.W. Rectifier)

Average Voltage = E_{peak} X .636 (For F. W. Rectifier)

EXAMPLE:

5 VOLTS/DIV setting

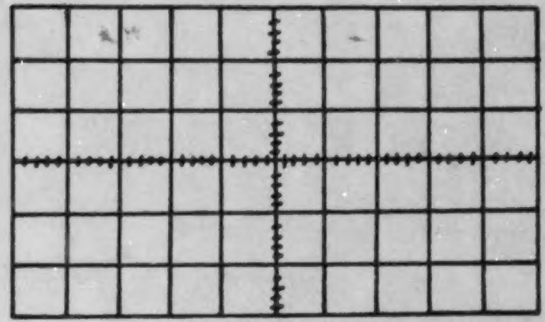
3 cm amplitude observed on the oscilloscope

5 x 3 = 15 volts

15 x 10 (probe atten.) = 150 volts (actual)

(3) Ripple amplitude is equal to the peak output voltage in unfiltered power supplies.

d. Draw the output waveform that appears on the oscilloscope on graph #2, show ripple amplitude and frequency.



GRAPH #2
HALF-WAVE UNFILTERED

e. Compare graphs #1 and #2 to check your calculations with actual measurements. If they do not agree, recheck your calculations.

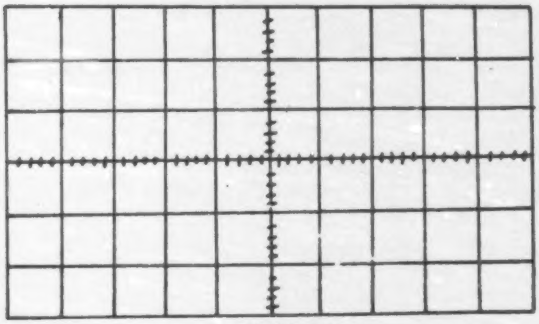
4. Activity

a. Set up the trainer to function as a full-wave unfiltered rectifier by setting the switches and controls to the following positions.

CONTROL	POSITION
(1) S101	OFF
(2) S102	FW
(3) S103	0 (CENTER)
(4) S104	CENTER
(5) S105	0 (CENTER)
(6) R104	FULLY CLOCKWISE

NOTE. Leave the test equipment hookup and switches in the same positions as previously stated for half-wave rectification.

b. Calculate and draw 3 cycles of the output waveform on graph #3, showing the output voltage, ripple amplitude, and frequency that should appear at TP108, with 140 V AC, 60 hertz, input to the rectifiers. (Use formulas to determine amplitude.)



GRAPH #3

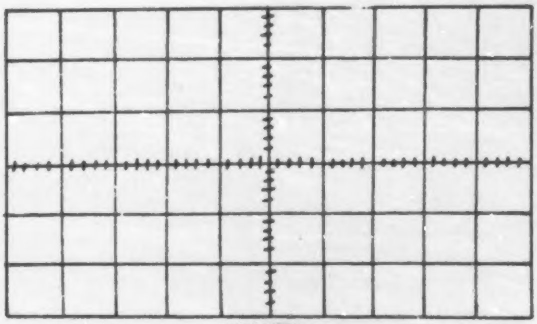
c. Turn S101 to the ON position and measure and record the output.

(1) Multimeter = ________ V_{av}

(2) Oscilloscope = ________ V_{pk}

(3) Number of Positive Pulses ______

d. Draw the output waveform that appears on the oscilloscope on graph #4. Show ripple amplitude and frequency.



GRAPH #4
FULL-WAVE UNFILTERED

e. Compare graphs #3 and #4 to check your calculations with actual measurements. If they do not agree, recheck your calculations.

5. Activity

a. Measure the output voltage and ripple amplitude of a filtered half-wave rectifier.

(1) Change S102 to the half-wave position (HW)

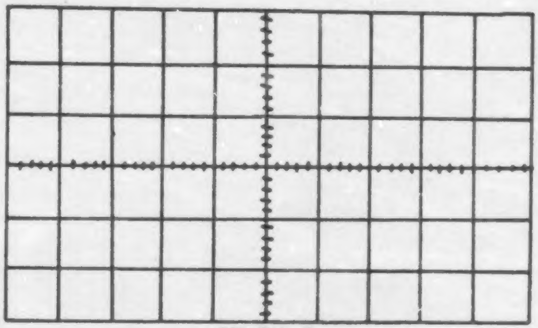
(2) Change S105 to the 5μF position and observe the effect of adding a capacitive filter to the rectifier.

(3) Measure and record the output waveform:

(a) Multimeter = ________ V_{av}

(b) Ripple Amplitude ______ V_{pk-pk}

(4) Draw the output waveform that appears on the oscilloscope on graph #5 Show the values for E_{pk} and E_{av} and note the result by adding the 5μF capacitor.



GRAPH #5
HALF-WAVE FILTERED

(5) By comparing graph #2 (HW unfiltered) with graph #5 (HW filtered), what effect did adding the 5μF capacitor have on:

(a) Output voltage (E_{av})?

______ by ______ volts

(b) Ripple Amplitude (E_{pk-pk})

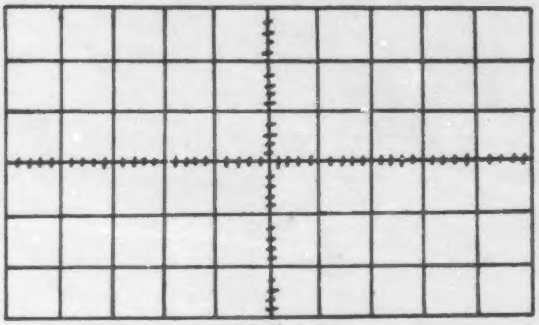
______ by ______ volts

(6) Change S105 to the 20μF position and measure the effects of increasing capacitance:

(a) Multimeter = ________ V_{av}

(b) Ripple Amplitude = ______ V_{pk-pk}

(7) Draw the waveform that appears on the oscilloscope as a result of increasing the capacitance to 20μF on graph #6



GRAPH #6
HALF-WAVE FILTERED

(8) By comparing graph #6 with graph #5, what effect did increasing the capacitance to 20μF have on:

(a) Output voltage (E_{av})?

______ by ______ volts

(b) Ripple Amplitude (E_{pk-pk})?

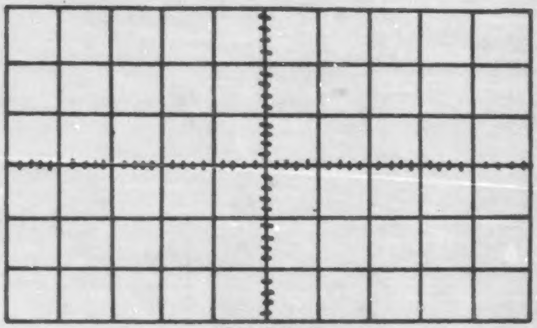
______ by ______ volts

d. Rotate R104 fully counter-clockwise and observe the effects of decreasing the load.

(1) Multimeter = ________ V_{av}

(2) Ripple Amplitude= ______ V_{pk-pk}

(3) Draw the waveform that appears on the oscilloscope as a result of decreasing the load on graph #7.



GRAPH #7
HALF-WAVE FILTERED
(DECREASED LOAD)

(4) By comparison of graphs #6 and #7, what effect did decreasing the load have on:

(a) Output Voltage (E_{av})?

______ by ______ volts

(b) Ripple Amplitude (E_{pk-pk})?

______ by ______ volts

6. Activity

a. Measure the output voltage and ripple amplitude of a filtered full-wave rectifier.

(1) Turn R104 fully clockwise.

(2) Change S102 to the full-wave (FW) position.

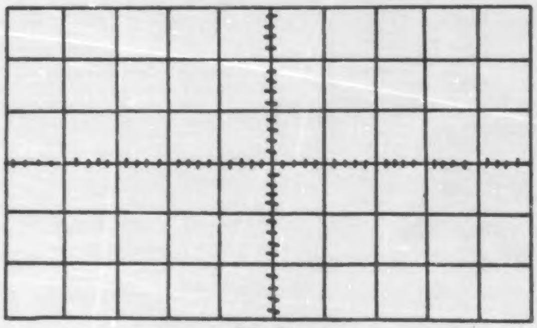
(3) Change S105 to the 5μF position and observe the effects of adding a capacitive filter to the rectifier.

(4) Measure and record the output waveform:

(a) Multimeter = ________ V_{av}

(b) Ripple Amplitude ______ V_{pk-pk}

(5) Draw the output waveform that appears on the oscilloscope on graph #8. Show the values for E_{pk} and E_{av} and note the results of adding the 5μF capacitor.



GRAPH #8
FULL-WAVE FILTERED

(6) By comparing graph #4 (FW unfiltered) with graph #8 (FW filtered) what effect did adding the 5μF capacitor have on:

(a) Output voltage (E_{av})?

______ by ______ volts

(b) Ripple amplitude (E_{pk-pk})?

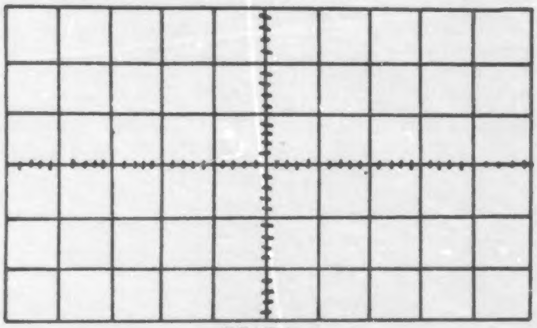
______ by ______ volts

(7) Change S105 to the 20μF position and measure the effects of increasing capacitance:

(a) Multimeter = ________ V_{av}

(b) Ripple Amplitude ______ V_{pk-pk}

(8) Draw the waveform that appears on the oscilloscope as result of increasing the capacitance to 20μF on graph #9.



GRAPH #9
FULL-WAVE FILTERED

(9) By comparing graph #8 to graph #9, what effect did increasing the capacitance to 20μF have on:

(a) Output voltage (E_{av})?

______ by ______ volts

(b) Ripple amplitude (E_{pk-pk})?

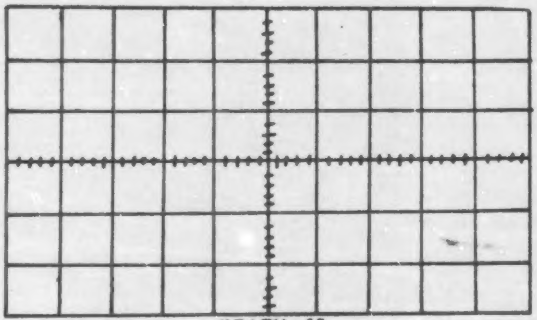
______ by ______ volts

b. Rotate R104 fully counter-clockwise and observe the effects of decreasing the load.

(1) Multimeter = ____________ V_{av}

(2) Ripple Amplitude = ________ V_{pk-pk}

(3) Draw the waveform that appears on the oscilloscope as a result of decreasing the load on graph #10.



GRAPH #10
FULL-WAVE FILTERED
(DECREASED LOAD)

(4) By comparison of graphs #10 and #9, what effect did decreasing the load have on:

(a) Output voltage (E_{av})?

______ by ______ volts

(b) Ripple Amplitude (E_{pk-pk})?

______ by ______ volts

7. Activity

a. Observe the effect of a choke input LC filter on a half-wave and full-wave rectifier and measure its output.

(1) Remove the 10:1 oscilloscope probe and replace it with the 1:1 probe.

(2) Rotate R104 to the fully clockwise position.

(3) Switch S104 to the L-101 position and measure the output:

(a) HALF-WAVE:

Multimeter = ______________ V_{av}

Ripple Amplitude ________ V_{pk-pk}

(b) FULL-WAVE:

Multimeter = ___________ V_{av}

Ripple Amplitude ________ V_{pk-pk}

b. Observe the effect of a Pi LC filter on a half-wave and full-wave rectifier and measure its output.

(1) Change S103 to the 20μF position and measure the output:

(a) HALF-WAVE:

Multimeter = ______________ V_{av}

Ripple Amplitude ________ V_{pk-pk}

(b) FULL-WAVE:

Multimeter = ______________ V_{av}

Ripple Amplitude ________ V_{pk-pk}

c. Observe the effect of a Pi RC filter on a half-wave and full-wave rectifier and measure its output.

(1) Change S104 to the R102 position and measure the output:

(a) HALF-WAVE:

Multimeter = ______________ V_{av}

Ripple Amplitude ________ V_{pk-pk}

(b) FULL-WAVE:

Multimeter = ______________ V_{av}

Ripple Amplitude ________ V_{pk-pk}

d. Observe the effect of increasing the size of the resistor in a Pi RC filter.

(1) Change S104 to the R101 position and measure the output.

(a) HALF-WAVE:

Multimeter = ______________ V_{av}

Ripple Amplitude ________ V_{pk-pk}

(b) FULL-WAVE:

Multimeter = ______________ V_{av}

Ripple Amplitude ________ V_{pk-pk}

CONFIRM THE LABORATORY EXERCISE RESULTS WITH THE INSTRUCTOR.

MODULE SELF-CHECK

QUESTIONS:

1. In a half-wave rectifier circuit, what is the output peak voltage equal to:

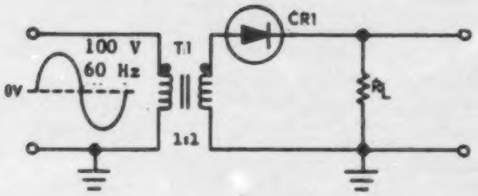


Figure 34-5. Half-Wave Rectifier

2. Calculate the peak output voltage for the circuit in figure 34-5.

3. What is the output peak voltage of a full-wave bridge rectifier equal to?

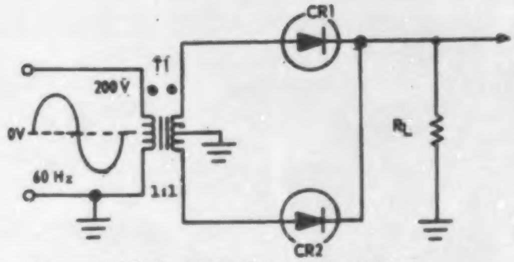


Figure 34-6. Full-Wave Rectifier

4. Calculate the peak output voltage for the circuit in figure 34-6.

5. What is the peak output voltage of a full-wave bridge rectifier equal to?

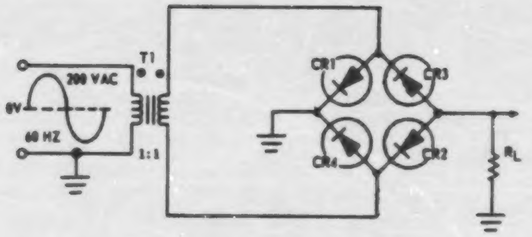


Figure 34-7. Full-Wave Bridge Rectifier

6. Calculate the peak output voltage for the circuit in figure 34-7.

7. Identify the ripple frequencies for following rectifiers with 60 Hz inputs.

Half-wave ______________ PPS

Full-wave ______________ PPS

Full-wave Bridge ______________ PPS.

8. Identify the direction of current flow in figure 34-5 by listing the components in proper order starting with R_L.

9. Select the correct output waveform from figure 34-8 for the half-wave rectifier shown in figure 34-5.

10. Select the statement that correctly describes an operation that occurs during the positive alternation of the input to figure 34-6.

____ a. CR-1 and CR-2 conduct at the same time.

____ b. Current flows through R_L, CR1 and the top side of T1 secondary to the center tap.

11. Select the correct output waveform from figure 34-8 for the full-wave rectifier shown in figure 34-6.

12. From figure 34-7, select the diodes which will conduct to control the direction of current flow through R_L during the negative alternation of the input.

___ a. CR1 and CR2

___ b. CR2 and CR4

___ c. CR3 and CR4

___ d. CR2 and CR3

13. Select the correct output waveform from figure 34-8 for the full-wave bridge rectifier shown in figure 34-7.

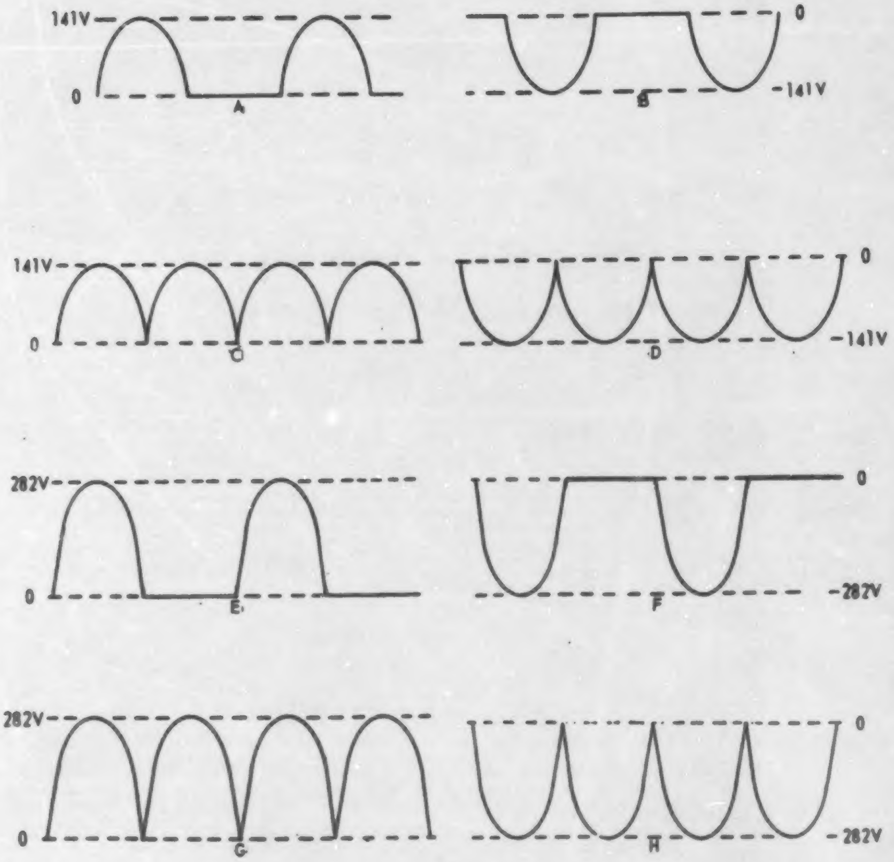

141V
0
A
0
-141V
B
141V
0
C
0
-141V
D
282V
0
E
0
-282V
F
282V
0
G
0
-282V
H

Figure 34-8. Output Waveforms

14. **Select the correct pair of diodes in figure 34-9 that will conduct when terminal A of the transformer is positive and terminal C is negative.**

___ a. CR1 and CR2

___ b. CR4 and CR5

___ c. CR3 and CR6

___ d. CR1 and CR4

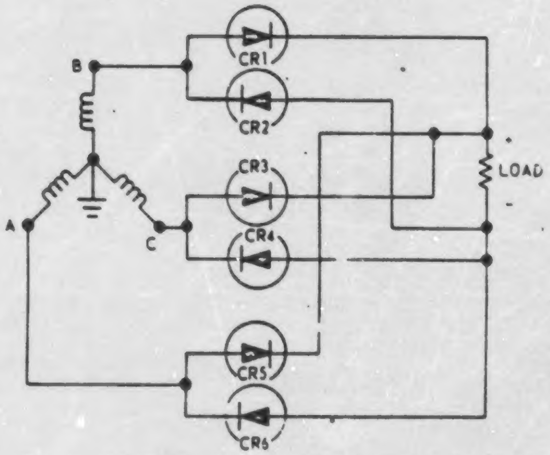
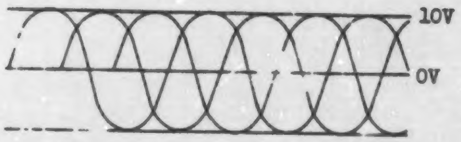
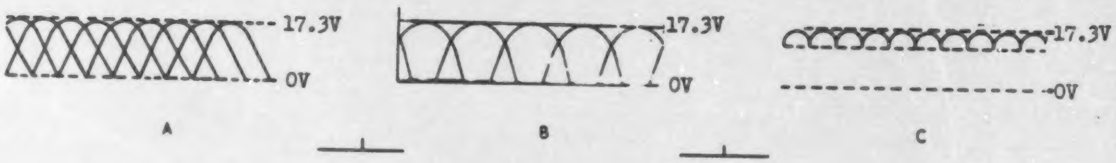


Figure 34-9. Three Phase Bridge Rectifier



INPUT



OUTPUT

Figure 34-10. Waveforms

15. Select the correct output waveform from figure 34-10 for the three phase rectifier shown in figure 34-9.

16. Select the statement that describes the effect of filtering on the output of a rectifier.

___a. Filters reduce the amplitude of the ripple voltage.

___b. Filters increase the peak output voltage.

___c. Filters are used to reduce the peak output voltage.

___d. Filters are used for impedance matching.

17. What is the output ripple frequency of a three-phase bridge rectifier with a 60 Hz input?

18. From the values given in the voltage doubler circuit in figure 34-11, determine the peak output voltage.

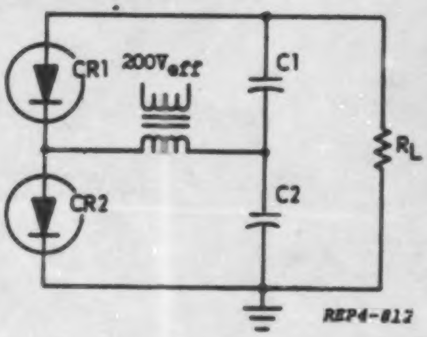
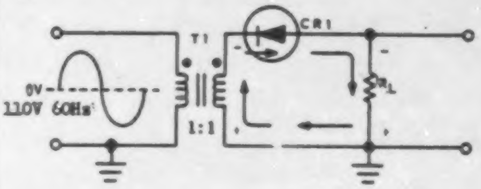


Figure 34-11. Voltage Doubler

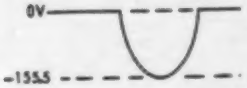
CONFIRM YOUR ANSWERS ON THE BACK PAGES.

ANSWERS TO A - ADJUNCT GUIDE

1. AC to Pulsating DC
2. Zero, infinite
3. True
4. Small, high
5. False
6. the peak voltage of the secondary
7. 110V x 1.414 = 155.5 V Peak
8. the peak voltage across the secondary of the transformer
9. 282.8 volts
10. One
11. True
12.


T1
CR1
0V
110V 60Hz
1:1
R_L

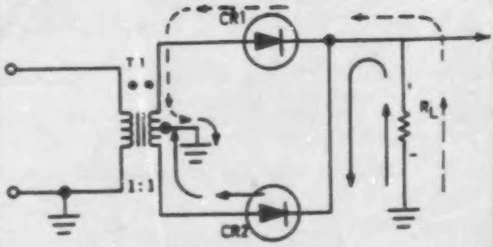
13.



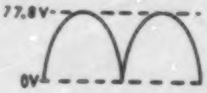
If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. True
2. center tapped
3. False
4. by reversing both diodes
5. 120 pps
6. 2 pps to 1 hertz
7. 400 volts
8. 127.2 volts
9. simple filtering
10. 110V x 1/2 = 55 x 1.414 = 77.8 V peak
11.


CR1
T1
1:1
CR2
R_L

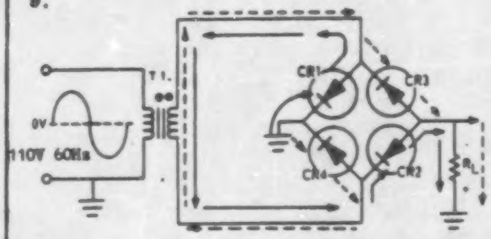
12.



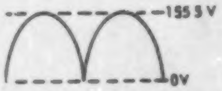
If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. Does not require a center-tapped secondary
2. four
3. True
4. 120 pps
5. 200V
6. True
7. False
8. 110V x 1.414 = 155.5 V Peak
9.


T1
0V
110V 60Hz
CR1
CR3
CR4
CR2
R_L

10.

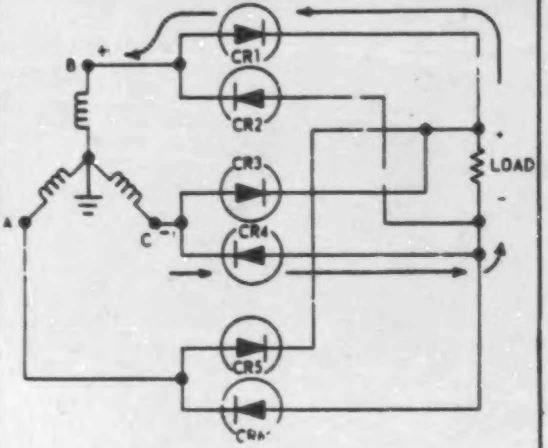


If you missed ANY questions, review the material before you continue.

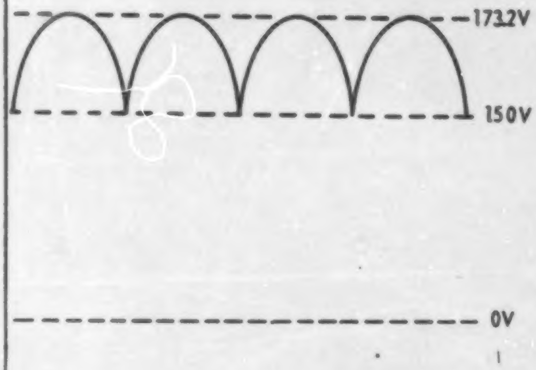
ANSWERS TO D - ADJUNCT GUIDE

1. 120°
2. voltage
3. current

4. 360 pps
5. True
6. small
7. 100V Pk (input) X 1.732 = 173.2 V Pk (output)
8.



9.



If you missed ANY questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1. pulsating DC to smooth DC.
2. decreases
3. short, long
4. True
5. True
6. True
7. lower, good
8. higher, less

If you missed ANY questions, review the material before you continue.

ANSWERS TO F - ADJUNCT GUIDE

1. LC
2. Two capacitors and one coil.
3. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO G - ADJUNCT GUIDE

1. True
2. 200 volts
3. 120 pps

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. Peak voltage of the transformer secondary.
2. 100 VAC x 1.414 = 141.4 V_p
3. Peak voltage of the transformer secondary.
4. 200 VAC x 1/2 = 100 VAC (each half of secondary) x 1.414 = 141.4V_p
5. Peak voltage of the transformer secondary.
6. 200 VAC x 1.414 = 282.8 V_p
7. 60 pps, 120 pps, 120 pps
8. R_L CR1 and T1 Secondary.
9. A
10. B
11. C
12. c
13. H
14. b
15. C
16. a
17. 360 pps
18. 565.5 V

HAVE YOU ANSWERED ALL THE QUESTIONS CORRECTLY? IF NOT REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.

PREPARE THE MAN

ATC GP 3AQR3X020-X 16

Prepared by Keesler TTC

KEP-GP-35

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 35

SOLID STATE POWER SUPPLY REGULATORS

1 August 1975

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

ATC Keesler 6-0265

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-35
1 August 1975

ELECTRONIC PRINCIPLES

MODULE 35
SOLID STATE POWER SUPPLY REGULATORS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

TITLE	PAGE
Overview	1
List of Resources	1
Adjunct Guide	1
Laboratory Exercise	3
Module Self-Check	7
Answers	10

OVERVIEW

1. SCOPE: Because the amplitude of DC supply voltage is critical in some equipments, the use of voltage regulators may be necessary. These circuits can maintain the output of a power supply at a predetermined voltage, even with changes of load or the input AC. This chapter discusses zener diode shunt regulators and electronic series regulators.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives:

a. Given a schematic diagram of a zener diode shunt regulator and a list of statements, select the statement which describes

(1) current path.

(2) purpose of the series resistor.

b. Given a schematic diagram of a series electronic voltage regulator and a list of statements, select the statements which give the effect on output voltage when the adjustment control is varied.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text V

AUDIO-VISUALS:

Television Lesson 30-361, Voltage Regulators (Solid State)

LABORATORY EXERCISE:

Laboratory Exercise 35-1, Solid State Power Supply Regulators

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

Supersedes KEP-GP-35 dated 1 June 1974. Stocks on hand will be used.

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ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

In the previous module you learned how power supplies converted AC to DC by rectification, reduced the DC ripple amplitude by filtration, and supplied the resultant DC to other circuits or loads. You also learned that the DC output of a power supply could be caused to vary by either a change in the input voltage or a change in load current requirements.

In either case, many electronic circuits operate satisfactorily with a moderate amount of deviation in the supply voltage. Other circuits are very critical and will not operate satisfactorily with even a slight amount of supply voltage deviation. With new generations of equipment this will become even more critical. Thus, the normal variations in power supply output will be unsatisfactory and will require the use of voltage regulating circuits and devices in most all power supplies.

In this module you will study the various circuits and components which are used in solid state voltage regulators.

A. Turn to the Student Text, Volume V, and read paragraphs 3-1 through 3-12. Return to this page and answer the following questions.

1. The name given to a family of diodes designed to operate with reverse breakdown voltage is ______________.

2. The reverse voltage at which the avalanche effect occurs in a zener diode is called the

____

3. With forward bias the zener diode operates the same as a ______________.

4. In a zener voltage regulator circuit with the diode placed in parallel with the load and in series with the current limiting resistor, the voltage delivered to the load is controlled by ______________

5. Several regulated voltages can be obtained from a single rectifier power supply by connecting several zener diodes in series. (T) (F)

6. What type of circuits are used in conjunction with zener diodes in voltage regulators to overcome the zener's limitation?

7. What are the two main limitations of zener diodes?

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

B. Turn to the Student Text, Volume V, and read paragraphs 3-14 through 3-26. Return to this page and answer the following questions.

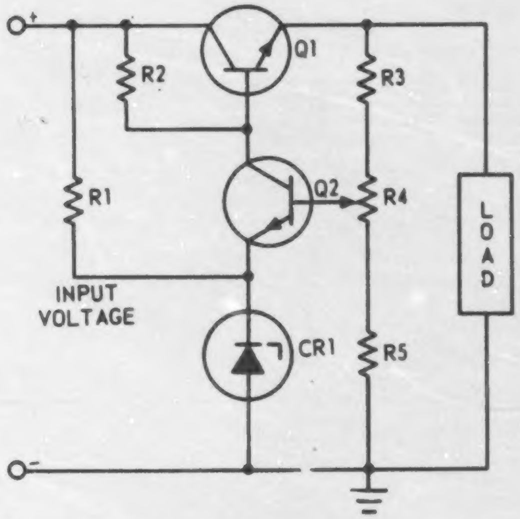

Figure 35-1. Electronic Voltage Regulator

(Use figure 35-1 to answer the following questions.)

1. Where does Q2 receive its reference voltage from?

_____

_____

_____

2. What controls the conduction of Q2?

_____

_____

3. What is the purpose of R1?

_____

_____.

4. Which component is referred to as the series regulator?

_____

5. Which component is referred to as the "differential" or "error" amplifier?

_____

6. At what point is the error signal generated?

_____.

7. How can the output voltage level be adjusted?

_____

8. If the arm of R4 is moved up, the forward bias on Q2 would _____

_____

9. If the arm of R4 is moved down, the resistance of Q1 will _____

causing the output voltage to _____.

_____

10. If the resistance of Q1 increases, the output voltage will _____

_____

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

_____

C. Turn to Laboratory Exercise 35-1 and complete all sections before returning to this page. If you have any difficulty, contact your instructor. The material in this exercise is arranged in the same sequence as that in your text so you may be able to apply the theory you learned to the actual circuit. This circuit is truly representatve of the voltage regulation circuits that you will encounter in many types of equipment in the field, thus a thorough understanding of the circuits' components with their functions and limitations is necessary.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

_____

LABORATORY EXERCISE 35-1

OBJECTIVE:

Given an electronic voltage regulator and multimeter, measure and observe the effect on the output voltage when the input voltage is varied and when the load is varied.

EQUIPMENT:

Electronic Voltage Regulator Trainer 5797
Multimeter
Variac

REFERENCE:

Student Text, Volume V, Chapter 3.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Analysis of the trainer

a. The schematic diagram of the electronic voltage regulator trainer is shown in figure 35-2.

b. The trainer contins a full-wave bridge rectifier stage, a voltage regulator stage and a load resistor and meter for monitoring load current.

c. The input voltage can be varied by insertion of a Variac between the trainer and AC source outlet.

d. The load can be varied by adjusting load resistor (rheostat) R8.

2. Preparation of Equipment

a. Trainer

1. S1 .....OFF

2. S2 .....UP

3. S3 .....UP

4. R8 .....Rully Clockwise (CW)

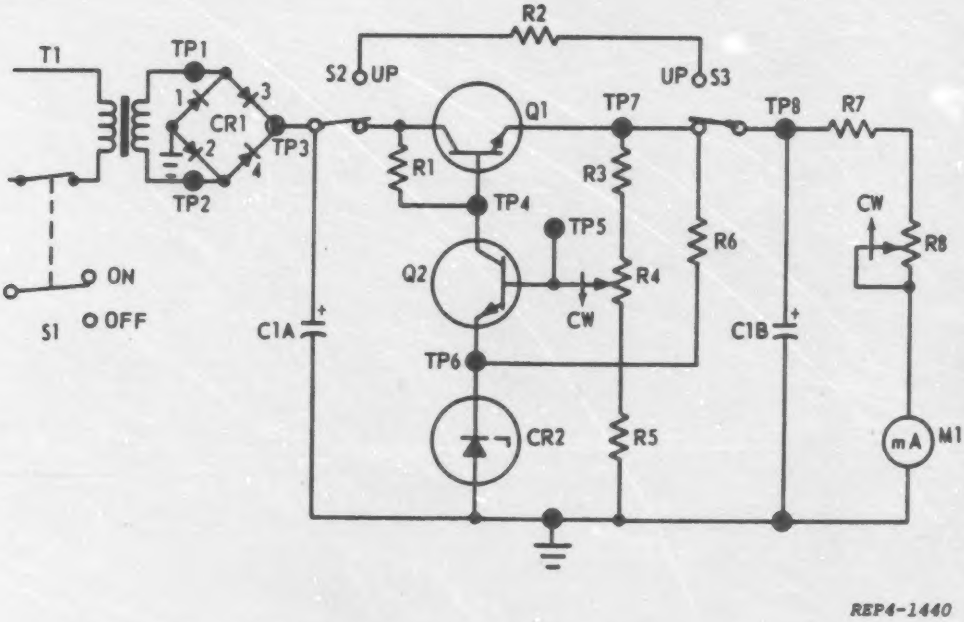
T1
TP1
1
3
CR1
2
4
TP2
TP3
R2
S2 UP
UP S3
Q1
TP7
TP8
R7
R1
TP4
TP5
R3
R6
CW
R8
Q2
R4
CW
ON
OFF
S1
C1A
C1B
TP6
CR2
R5
mA
M1
REP4-1440

Figure 35-2. Electronic Voltage Regulator

b. Multimeter

1. Function Switch .....AC

2. Range Switch 50

NOTE: ALWAYS MAKE YOUR MEASUREMENTS ON THE LOWEST RANGE POSSIBLE.

c. Variac

1. Power Switch.....OFF

2. Dial.....Fully Counter-Clockwise

d. Interconnections

1. Plug the trainer power cord into the Variac.

2. Turn the Variac power switch ON.

3. Turn the trainer power switch (S1) ON.

The trainer is now a bridge rectifier (CR1) with a Pi-type RC filter (R2, C1A, C1B) and a resistive load (R7 and R8) and the input voltage can be adjusted (Variac).

3. Activity

Instruction:

Connect the multimeter to TP-1 and TP-2. Adjust the Variac until the voltage on the secondary of T1 is 15 VAC.

a. Minimum Input Voltage is 15 VAC.

Instruction:

Adjust the Variac clockwise for maximum voltage. Measure the voltage on the secondary of T1.

b. Maximum Input Voltage ________ VAC.

Instruction:

Disconnect the multimeter. Place the function switch on DC 20k ohms/volt. Connect the multimeter across the load (Negative lead to ground, Positive lead to TP-8). Measure the maximum output voltage of the rectifier and filter circuit.

c. Maximum Output Voltage ________ VDC.

Instruction:

Disconnect the multimeter. Place the function switch on AC. Connect the multimeter to TP-1 and TP-2 on the trainer. Adjust the Variac counter-clockwise for 15 VAC on the secondary of T1. Disconnect the multimeter. Place the function switch on DC. Measure and record the output of the rectifier and filter circuit (Negative lead to ground, Positive lead to TP-8).

d. Minimum Output Voltage ________ VDC.

e. Record the minimum AC input voltage (Step a) ________ VAC.

Record the maximum AC input voltage (Step b) ________ VAC.

The total change in the input AC voltage was ________ VAC.

f. Record the maximum DC output voltage (step c) ________ VDC.

Record the minimum DC output voltage (step d) ________ VDC.

The total change in the output DC voltage was ________ VDC.

g. In an UNREGULATED power supply, as the input AC voltage changes, the output DC voltage CHANGES/REMAINS RELATIVELY CONSTANT.

Instruction:

Measure and record the DC output voltage (with multimeter) and the load current (M1 on the trainer).

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h. DC Output Voltage ______________

VDC, Load Current ______________ mA.

Instruction:

Adjust R8 fully counter-clockwise (minimum load on the circuit). Measure and record the DC output voltage and the load current.

i. DC Output Voltage ______________

VDC, Load Current ______________ mA.

j. Record the maximum current thru the

load (step h) ______________ mA.

Record the minimum current thru the

load (step i) ______________ mA.

The total change in the load current

was ______________ mA.

k. Record the maximum voltage across the

load (step i) ______________ VDC.

Record the minimum voltage across

the load (step h) ______________ VDC.

The total change in load voltage was

______________ VDC.

l. In an UNREGULATED power supply, as the load is varied, the output voltage

______________.

Instruction:

Place S2 and S3 on the trainer to the DOWN position. This places the ELECTRONIC VOLTAGE REGULATOR in the circuit. Adjust R4 fully counter-clockwise. Measure and record the load voltage and load current.

m. Minimum Input AC Voltage (Step a) ______________ VAC

LOAD VOLTAGE ______________ VDC

LOAD CURRENT ______________ mA

Instruction:

Adjust the Variac clockwise for maximum input AC voltage. Measure and record the load voltage and load current.

n. Maximum Input AC Voltage (step b)

______________ VAC.

LOAD VOLTAGE ______________ VDC

LOAD CURRENT ______________ mA

o. The AC input voltage changed (Step b

minus Step a) ________ VAC, the load voltage

changed (step n minus step m) ________

VDC, and the load current changed (step n

minus step m) ________ mA.

Instruction;

Adjust R8 fully clockwise (maximum load on the Electronic Voltage Regulator). Measure and record the load voltge and load current.

p. LOAD VOLTAGE ______________ VDC.

LOAD CURRENT ______________ mA.

q. The load current changed (step p minus

step n) ______________ mA, and the load

voltage changed (step n minus step p) ________

VDC.

r. In a REGULATED power supply, the

output voltage remains relatively constant

even though the input ______ or the ______

changes by a large amount.

Instruction:

Measure the voltage across the Zener diode, CR-2.

s. With maximum AC input voltage, the voltage across CR-2 is ____________VDC.

Instruction:

Adjust the Variac counter-clockwise for 15 VAC on the secondary of T1.

t. With minimum AC input voltage, the voltage across CR-2 is ____________VDC.

u. The voltage across the Zener diode remains relatively ____________________ even though the input voltages change by a large amount.

Instruction:

Place the multimeter across the load. Adjust the voltage adjust control (R4) for maximum DC output voltage.

v. Maximum Output Voltage ______VDC.

4. Summary

Adjust the Variac clockwise for maximum input AC voltage.

Adjust R4 until the output of the EVR is 10 VDC.

Measure the voltage at TP3 ____________.

Measure the voltage at TP4 __________.

If you have any questions, call the instructor.

5. Questions

Circle the correct option for each multiple choice question.

a. If Q1 is open, the output

(1) voltage will be maximum

(2) current will be minimum

b. The purpose of CR-2 is to

(1) hold the current to the emitter of Q2 constant.

(2) hold the output current constant.

(3) keep the voltage on the emitter of Q2 constant.

c. If R-7 is open, the load current will be

(1) normal

(2) maximum

(3) zero

d. If Q1 is shorted

(1) load voltage will be maximum

(2) load voltage will be normal

(3) load current will be zero

6. Securing of the Trainer and Test Equipment

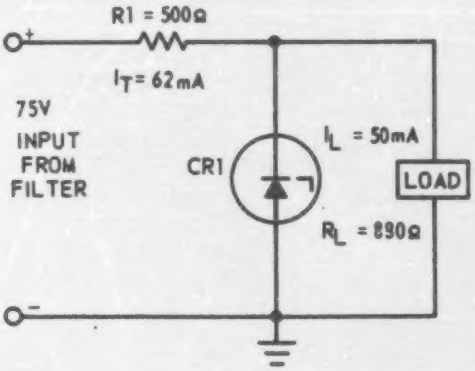
a. Unplug the equipment. Be sure all equipment is neatly arranged.

b. Review the objectives and questions of this project.

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

MODULE SELF-CHECK

QUESTIONS:



REP4-1439

Figure 35-3. Zener Voltage Regulator Circuit

1. The normal current path for figure 35-3 is from:

a. Ground through CR1 and R1 to the positive side of the input filter.

b. The positive side of the input filter through R1, the load and ground.

c. The negative side of the input filter through CR1, the load and R1, to the positive side of the input filter.

d. The negative side of the input filter, through the load and R1 to the positive side of the input filter.

2. The purpose of the series resistor R1, in figure 35-3 is to:

a. Increase current to the load.

b. Limit the current through the zener diode.

c. Decrease RL.

d. Increase RL.

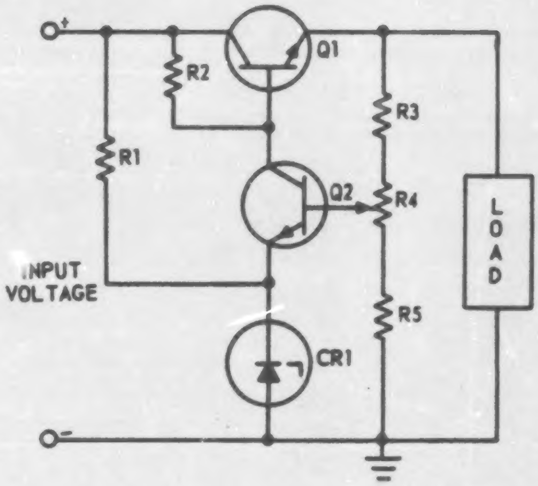


Figure 35-4. EVR

3. When the arm of R4 in figure 35-4 is moved upward, the voltage across the load will:

a. decrease

b. increase

c. remain the same

4. When the arm of R4 in figure 35-4 is moved downward, the voltage across the load will:

a. decrease

b. increase

c. remain the same

5. An increase in the load of figure 35-4 would have the same effect on Q1 as moving the arm of R4 in which direction?

6. A decrease in the load of figure 35-4 would have the same effect on Q1 as moving the arm of R4 in which direction?

7. An increase in the input voltage in figure 35-4 wold have the same effect on Q1 as moving the arm of R4 in which direction?

8. A decrease in the input voltage in figure 35-4 would have the same effect on Q1 as moving the arm of R4 in which direction?

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

NOTES

ANSWERS TO A - ADJUNCT GUIDE

1. Zener
2. reverse breakdown voltage
3. PN junction diode
4. BVR value of the zener diode
5. True
6. amplifier circuits
7. current operating range, voltage amplitude rating.

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. the zener diode
2. voltage at the arm of R4
3. current limiting for CR1
4. Q1
5. Q2
6. arm of R4
7. by adjusting the arm of R4
8. increase
9. decrease, increase
10. decrease

If you missed ANY questions, review the material before you continue.

ANSWERS TO LAB EXERCISE 35-1
(NOTE: If your answers do not agree with those listed, ask your instructor for assistance)

3.
   - b. 28 VAC
   - c. 29.8 VDC
   - d. 15.5VDC
   - e. 28VAC, 15VAC and 13VAC
   - f. 29VDC, 15.5VDC and 14.3 VDC
   - g. changes
   - h. 15.5VDC and 16mA
   - i. 21.5VDC and 2mA
   - j. 16mA, 2mA and 14mA
   - k. 21.5VDC, 15.5VDC and 6VDC
   - l. varies
   - m. 15VAC, 9VDC and 1mA
   - n. 29 ± 1VAC, 9.2VDC and 1mA
   - o. 13VAC, .2VDC and Zero
   - p. 9.2VDC and 9mA
   - q. 8mA and Zero
   - r. voltage, load
   - s. 8.2VDC
   - t. 7.9VDC
   - u. Constant
   - v. 11VDC

4. TP3-37.5 and TP4-10.2

5. a. (2), b. (3), c. (3), d. (1)

ANSWERS TO MODULE SELF-CHECK

1. c
2. b
3. a
4. b
5. downward
6. upward
7. upward
8. downward

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-36

Technical Training

Electronic Principles (Modular Self-Paced)

Module 36

TROUBLESHOOTING SOLID STATE POWER SUPPLIES

December 1975

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

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Radar Principles Branch
Keesler Air Force Base, Mississippi

Guidance Package 3AQR3X020-X
KEP-GP-36
December 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 36

TROUBLESHOOTING SOLID STATE POWER SUPPLIES

This guidance package is designed to guide you through this module of the Electronic Principles Course. This guidance package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Title	Page
Overview	1
List of Resources	1
Adjunct Guide	1
Laboratory Exercise	2
Answers	13

OVERVIEW

1. SCOPE. This module discusses the techniques used in troubleshooting power supplies. The laboratory exercise provides practical experience in troubleshooting filtered half-wave and full-wave rectifiers and electronic voltage regulators (EVR).

2. OBJECTIVES. Upon completion of this module, you should be able to satisfy the following objectives:

a. Given a multimeter, oscilloscope, schematic diagram, and a trainer having an inoperative solid state half-wave filtered power supply, determine the faulty component two out of three times.

b. Given a multimeter, oscilloscope, schematic diagram, and a trainer having an inoperative solid state full-wave regulated and filtered power supply, determine the faulty component two out of three times.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following.

READING MATERIALS:
Digest
Adjunct Guide with Student Text V

AUDIO VISUALS:
Television Lesson 30-352A, Power Supplies and Filters (Troubleshooting)
Television Lesson 30-352B, Voltage Doubler (Troubleshooting)

LABORATORY EXERCISE:
Laboratory Exercise 36-1, Troubleshooting Solid-State Power Supplies
Student Handout KEP-HO-36, Troubleshooting Solid-State Power Supplies.

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE PROGRESS CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

Supersedes KEP-GP-36, 1 August 1974. Supplies on hand will be used.

ADJUNCT GUIDE

INSTRUCTIONS

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this guidance package.

Contact your instructor if you experience any difficulty.

Begin the program.

Previous modules discussed rectification, filtration, and regulation as functional sections of power supplies which, when combined, make a complete power supply. Emphasis was placed on learning the theory of operation, circuit analysis, and interaction of the sections.

At this point, you should know the operation of a half-wave or full-wave, filtered and regulated power supply. Like other electronic circuits, power supplies are subject to failure. Knowing the correct operation should help you determine the symptoms of a malfunction. Once the symptom is recognized, isolation of the faulty circuit and component can be determined and repaired. In this module you will study troubleshooting procedures which will help you locate faulty components.

A. Turn to Student Text, Volume V, and read paragraphs 4-1 through 4-20. Return to this page and answer the following questions.

1. What will be the output from a half-wave rectifier with a shorted diode? ____________

2. What will be the output from a half-wave rectifier with an open diode? ____________

3. What is the output from a half-wave rectifier with a shorted filter capacitor?

____

4. What probable effect will a shorted filter capacitor have on the diode in an unfused, half-wave rectifier? ____________

5. An open filter capacitor in a half-wave rectifier will cause the average output voltage to ______________________.

6. What would be the most probable cause of high ripple amplitude in a half-wave rectifier? ______________________

7. A full-wave rectifier with an open diode acts as a/an ______________________.

8. What is the first component that should be checked in a full-wave rectifier that has no output? ____________________

9. What are the two most probable causes of a blown fuse in a full-wave rectifier?

a. ______________________

b. ______________________

CONFIRM YOUR ANSWERS.

B. Turn to Student Text, Volume V, and read paragraphs 4-21 through 4-32. Return to this page and answer the following questions.

1. What would be the most probable cause of an electronic voltage regulator having a higher than normal output and no regulation:

____

2. What should be the first two checks made on a voltage regulator suspected of malfunctioning?

a. ______________________

b. ______________________

3. Given a voltage regulator which functions normally under no-load conditions, what would be the suspected problem if, when the load is connected, the output voltage decreased excessively and would not regulate?

CONFIRM YOUR ANSWERS.

C. Perform Laboratory Exercise 36-1 and complete all sections. The material in this exercise is arranged to give you practical experience in troubleshooting analysis of malfunctioning power supplies similar to what you will encounter in the field. If you have any difficulty, contact your instructor.

LABORATORY EXERCISE 36-1

OBJECTIVES:

1. Given a multimeter, oscilloscope, schematic diagram, and a trainer having an inoperative solid state half-wave filtered power supply, determine the faulty component two out of three times.

2. Given a multimeter, oscilloscope, schematic diagram, and a trainer having an inoperative solid state full-wave regulated and filtered power supply, determine the faulty component two out of three times.

EQUIPMENT:

1. Power Supply Troubleshooting Trainer (5927)

2. Oscilloscope

3. Multimeter

4. Meter Panel (4567)

REFERENCES:

Student Text, Volume V, Chapter 4

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Trainer Analysis:

a. The power supply troubleshooting trainer, shown in figure 1 of Student Handout HO-36, consists of four functional sections.

(1) Rectifier.
(2) Filter.
(3) Voltage Regulator.
(4) Loading Circuit.

b. Trainer controls and switches are as follows. (Locate each component on figure 1 in Student Handout HO-36 and circle with pencil.)

(1) S-1 - OFF/ON, power switch in the primary of T-1.

(2) S-2 - FW/HW, full-wave, half-wave selector in series with CR-1.

(3) R-4 - Output voltage adjust in the base circuit of Q-2.

(4) R-8 - Load adjust in the output circuit.

c. The trainer has built-in troubleshooting capabilities. A compartment at the rear of the trainer contains switches used to insert troubles. The following simulated troubles are available:

(1) Shorted filter choke L-1.
(2) Open filter choke L-1.
(3) Bypassed Zener diode CR-3.
(4) Open filter capacitors C-1 and C-2.
(5) Open transistor collector Q-2.
(6) Open center tap of transformer T-1 secondary.
(7) Open voltage adjust potentiometer R4.
(8) Open fuse.
(9) Open load resistor R-8.

NOTE: Troubleshooting involves the use of test equipment to make voltage and current measurements. These measurements are then analyzed to determine the probable cause of malfunction. Test equipment may alter circuit characteristics and cause slight changes in current and voltage levels.

2. Preparation of Equipment

a. Oscilloscope Controls	Position
(1) SCALE ILLUM	Clockwise
(2) TRIG SELECT LEVEL	CH1+ AUTO
(3) TIME/CM	5 mS CAL
(4) CH1 Vertical Position	Mid-Position
(5) CH2 Vertical Position	OFF
(6) SEPARATE-CH1&CH2	SEPARATE
(7) AC-ACF-DC	AC
(8) CHOP-ALT	ALT
(9) AC-GND-DC(CH1)	AC
(10) AC-GND-DC(CH2)	GND
(11) VOLTS/CM	.2 V CAL

b. Trainer Controls	Position
(1) FW/HW	HW (Half-wave)
(2) Trouble switches (S-3 thru S-11)	Down

c. Multimeter Controls	Position
(1) FUNCTION	DCV 20 kΩ/V
(2) RANGE	10 V

d. Ground the oscilloscope to the trainer.

e. Connect the 0-10 mA jack on the ammeter panel to J-1 of the trainer.

f. Insert multimeter leads at TP-10 and GND (TP-13) of the trainer. (OBSERVE POLARITY.)

g. Connect the trainer to the power source.

3. Activity

a. Trainer Adjustment

(1) Place power switch to ON.

(2) Adjust R-4 for 5-volt reading on the multimeter (TP-10 to GND).

(3) Adjust R-8 for 2 mA on the ammeter panel.

NOTE: Interaction of these controls may require readjustment.

b. Half-Wave Normal Operation

In order to establish normal voltages and currents for your trainer, follow the procedures and record values in the NORMAL MEASURED column of the Half-Wave Troubleshooting Summary Chart 1 in the Student Handout HO-36.

(1) Secondary voltage (AC) TP-3 to TP-4 (Multimeter).

(a) Set the multimeter FUNCTION to ACV 1 k Ω/V and RANGE to 50.

(b) Measure and record the voltage from TP-3 to TP-4.

(2) Rectified voltage (DC) TP-5 to GND (Multimeter).

(a) Set the multimeter FUNCTION to DCV 20 kΩ/V and RANGE to 50.

(b) Measure and record the voltage from TP-5 to GND. (OBSERVE POLARITY.)

(3) Ripple voltage (peak to peak) TP-5 to GND (Oscilloscope).

(a) Oscilloscope VOLTS/CM set previously (.2 V, CAL).

(b) Use CH1 to measure and record the peak-to-peak ripple voltage from TP-5 to GND. (Oscilloscope was grounded in step 2d.)

(4) Filtered voltage (DC) TP-6 to GND (Multimeter).

(a) Multimeter FUNCTION and RANGE previously set. (DCV 20kΩ/V & 50.)

(b) Measure and record the voltage from TP-6 to GND. (OBSERVE POLARITY.)

(5) Filtered ripple voltage (peak to peak) TP-6 to GND (Oscilloscope).

(a) Oscilloscope VOLTS/CM previously set (.2 V, CAL).

(b) Use CH1 to measure and record the peak-to-peak ripple voltage from TP-6 to GND. (Oscilloscope was grounded in step 2d.)

(6) Voltage dropped by choke L-1 (DC) TP-5 to TP-6 (Multimeter).

(a) Set the multimeter RANGE to 10 (FUNCTION at DCV 20kΩ/V).

(b) Measure and record the voltage from TP-5 (Pos) to TP-6 (Neg). (OBSERVE POLARITY.)

(7) Output voltage (DC) TP-10 to GND. (Multimeter)

(a) Multimeter FUNCTION and RANGE previously set (DCV 20kΩ/V & 10).

(b) Measure and record the voltage from TP-10 to GND. (OBSERVE POLARITY.)

(8) Output current (mA) J-1 (Meter Panel).

(a) J-1 of the trainer previously connected to meter panel.

(b) Measure and record the current at J-1.

COMPARE YOUR NORMAL MEASURED READINGS WITH THE NOMINAL VALUES LISTED ON CHART 1 IN THE STUDENT HANDOUT. IF YOUR MEASURED VALUES DIFFER MORE THAN 20 PERCENT FROM THE NOMINAL VALUES, CONSULT YOUR INSTRUCTOR.

c. Trouble 1 - Open Fuse.

(1) Insert OPEN FUSE trouble by placing S-3 in the UP position. Locate this switch on Figure 36-1, Power Supply Rectifier.

(2) Follow the same procedures used in measuring normal trainer test points, step 3b. Record values in the Open Fuse column of the Troubleshooting Summary Chart 1 in Student Handout HO-36.

(3) Use the trainer diagram in conjunction with the Troubleshooting Summary Chart 1 of the student handout to analyze the trouble.

(4) Answer the following questions:

(a) What measurements were NOT necessary for this trouble? Why?

(b) Replacing the fuse may not correct the trouble. Why?

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

d. Trouble 2 - Open Transformer Secondary Center Tap.

(1) Insert OPEN TRANSFORMER CENTER TAP (CT) by placing S-4 UP. Locate this switch on figure 36-1.

(2) Follow the same procedures used in measuring normal trainer test points, step 3b. Record values in the Open T-1 CT column of the Troubleshooting Summary Chart 1 in the Student Handout HO-36.

(3) Use the trainer diagram and the Troubleshooting Summary Chart 1 of the student handout to analyze the trouble.

(4) Answer the following questions:

(a) What amplitude was measured at TP-5? Why?

____

____

____

____

____

____

____

____

____

____

____

____

(b) Why was voltage measured across T-1 secondary normal (TP3 to TP4) with the CT open?

____

____

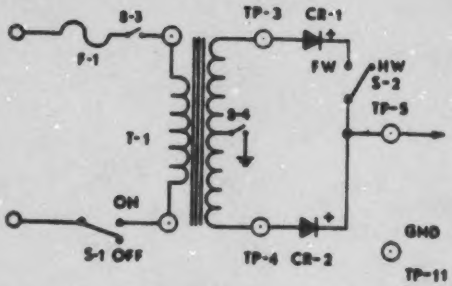

Figure 36-1. Power Supply Rectifier

(c) What other component(s) could malfunction to produce these readings?

____

____

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

e. Trouble 3 - Open Filter Choke L-1.

(1) Insert OPEN FILTER CHOKE L-1 with S-5 and locate on Figure 36-2, Power Supply Filter.

(2) Record values in the appropriate column of chart 1 in HO-36.

(3) Use the trainer diagram and compare recorded measurements to analyze malfunction.

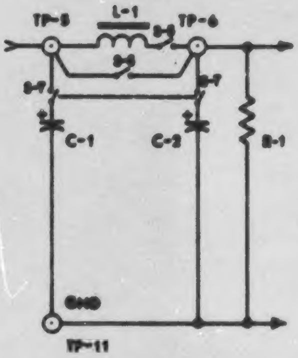

Figure 36-2. Power Supply Filter

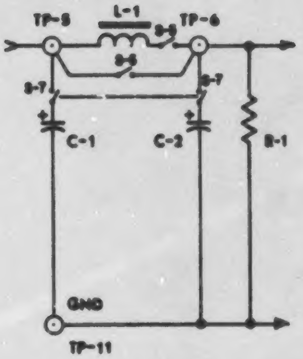

Figure 36-2. Power Supply Filter

(4) Answer the following questions:

(a) Why was there an increase in voltage at TP-5?

(b) Why is there no output at TP-6 with an open filter choke?

(c) Why is there no ripple voltage reading at TP-5 with an open filter choke?

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

f. Trouble 4 - Shorted Filter Choke L-1.

(1) Insert SHORTED FILTER CHOKE L-1 with S-6 and locate on figure 36-2.

(2) Record values in the appropriate column of chart 1 in HO-36.

(3) Use the trainer diagram and the recorded measurements to analyze malfunction.

(4) Answer the following questions:

(a) Does the ripple voltage at TP-5 increase, decrease, or remain the same? Why?

(b) Does the ripple voltage at TP-6 increase, decrease, or remain the same? Why?

(c) Why does the output voltage at TP-10 increase slightly?

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

g. Trouble 5 - Open Filter Capacitors (C-1 & C-2).

(1) Insert OPEN FILTER CAPACITORS C-1 and C-2 with S-7. Locate this switch (two sections) on figure 36-2.

(2) Record values in the appropriate column of chart 1 in HO-36.

(3) Use the trainer diagram and the recorded values to analyze the malfunction.

(4) Answer the following questions:

(a) Ripple voltage increased with open capacitors C1 and C2. Why?

(b) Why is the voltage at TP-6 lower than normal?

(c) Why is the output voltage at TP-10 lower than normal?

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

h. Trouble 6 - Open Load Resistor R-8.

(1) Check trainer output voltage and current (5 V and 2 mA). If necessary, use procedure 3a to adjust the output.

(2) Insert OPEN R-8 with S-11 and locate on figure 36-3, Power Supply Load.

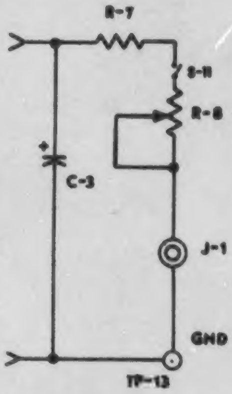

Figure 36-3. Power Supply Load

(3) Record values in the appropriate column of chart 1 in HO-36.

(4) Use the trainer diagram and the recorded measurements to analyze malfunction.

(5) Answer the following questions:

(a) What is the output current at J-1 with open load resistor? Why?

(b) How can this trouble be distinguished from other troubles that have the same value for output current?

(c) Does the ripple voltage at TP-5 change from normal? If so, why?

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

AT THIS POINT YOU MAY TAKE THE FIRST OF TWO PROGRESS CHECKS ON TROUBLESHOOTING POWER SUPPLIES. IF YOU WISH, YOU CAN COMPLETE LABORATORY EXERCISE AND TAKE BOTH PROGRESS CHECKS.

i. Full-Wave Operation.

(1) Place the FW/HW switch on the trainer to FW (full-wave) position.

(2) Turn to the Full-Wave Troubleshooting Summary Chart 2 in the student handout and use procedure 3b to measure and record the first six NORMAL MEASURED values. After recording the data, return to this page and complete Troubleshooting Summary Chart 2.

(3) Voltage dropped by transistor Q-2 (DC) TP-7 to TP-8 (Multimeter).

(a) Set the multimeter FUNCTION to DCV 20kΩ/V and RANGE to 10.

(b) Measure and record the voltage from TP-7 (Pos) to TP-8 (Neg). (OBSERVE POLARITY.)

(4) Bias voltage for transistor Q-2 (DC) TP-8 to TP-9 (Multimeter).

(a) Set the multimeter RANGE to 2.5 (FUNCTION at DCV 20kΩ/V).

(b) Measure and record the voltage from TP-8 (Neg) to TP-9 (Pos). (OBSERVE POLARITY.)

NOTE: Some troubles will cause the bias on Q-2 to reverse polarity.

(5) Reference voltage at Zener diode CR-3 (DC) TP-8 to GND. (Multimeter)

(a) Set the multimeter RANGE to 10 (FUNCTION at DCV 20kΩ/V).

(b) Measure and record the voltage from TP-8 (Pos) to GND (Neg). (OBSERVE POLARITY.)

(6) Control Voltage (DC) TP-9 to GND (Multimeter).

(a) Multimeter FUNCTION and RANGE previously set (DCV 20k Ω/V and 10).

(b) Measure and record the voltage from TP-9 to GND. (OBSERVE POLARITY.)

(7) Steps 11 and 12 of Summary Chart 2 require measurement of output voltage and current. These levels were previously adjusted in steps 3a(2) and 3a(3). If the values are different than those indicated, readjust the output and record the values.

COMPARE YOUR NORMAL MEASURED READINGS WITH THE NOMINAL VALUES LISTED ON CHART 2 IN THE STUDENT HANDOUT. IF YOUR MEASURED READINGS DIFFER MORE THAN 20 PERCENT FROM THE NOMINAL VALUES, CONSULT YOUR INSTRUCTOR.

j. Trouble 1 - Open T-1 Center Tap.

(1) Use S-4 to insert trouble.

(2) Record values in the appropriate column of chart 2 in HO-36.

(3) Use the trainer and compare record measurements to analyze malfunction.

(4) Answer the following questions:

(a) What amplitude of voltage was measured at TP-10? Why?

(b) Was the voltage between TP-3 and TP-4 normal? Why?

(c) How could an ohmmeter be used to confirm this trouble?

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

k. Trouble 2 - Open L-1 (S-5 UP).

(1) Use the schematic diagram and the recorded measurements to analyze the trouble.

(2) Answer the following questions:

(a) Why did the voltage across C-1 increase?

(b) What is the voltage drop across R-1? Why?

(c) Why is there no ripple voltage at TP-5?

____

____

____

CONFIRM YOUR ANSWERS AN REMOVE THE TROUBLE.

l. Trouble 3 - Shorted L-1 (S-6 UP).

(1) Use the schematic diagram and the recorded measurements to analyze the trouble.

(2) Complete the following:

(a) The ripple voltage at TP-5 (INCREASED) (DECREASED) (REMAINED THE SAME).

(b) The ripple voltage at TP-6 (INCREASED) (DECREASED) (REMAINED THE SAME).

(c) The ripple voltage at TP-5 is (MORE THAN) (LESS THAN) (SAME AS) the ripple voltage at TP-6.

(d) The DC voltage at TP-6 increased

because ________________________________

____

____

____

____.

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

m. Trouble 4 - Open C1 and C2 (S7 - UP).

(1) Use schematic diagram and recorded measurements to analyze the trouble.

(2) Answer these questions:

(a) How can the ripple voltage be greater than the DC voltage at TP-5?

____

____

____

____

____

____

(b) Why is the ripple voltage at TP-6 less than at TP-5?

____

____

____

____

____

____

____

____

(c) What test should positive identify open filter capacitors?

____

____

____

____

____

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

n. Trouble 5 - Open Transistor Collector Q-2 (S-8 UP).

(1) Insert OPEN TRANSISTOR COLLECTOR Q-2 with S-6 and locate on figure 36-4, Power Supply Regulator.

(2) Use the schematic diagram and the recorded measurements to analyze the malfunction.

(3) Answer the following questions:

(a) What would be the approximate voltage from TP-7 to ground?

(b) Why was the output voltage (TP-10 to GND) much higher than normal?

(c) Does the ripple at TP-5 (INCREASE), (DECREASE), or (REMAIN THE SAME)? Why?

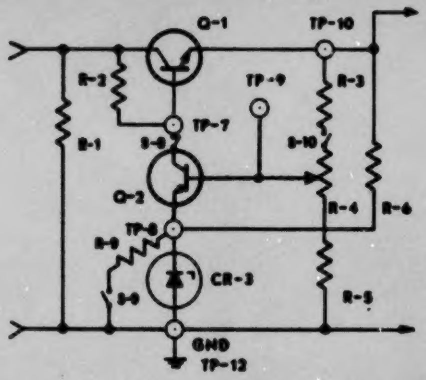

Figure 36-4. Power Supply Regulator

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

o. Trouble 6 - Bypassed Zener Diode CR-3 (S-9 UP).

(1) Locate this trouble on figure 36-4.

(2) Use the schematic diagram and the recorded measurements to analyze malfunction.

(3) Answer the following questions:

(a) Why does output voltage at TP-10 decrease?

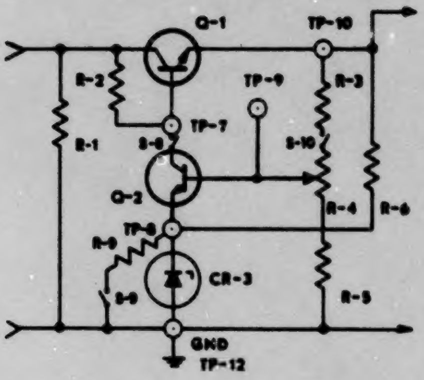

Figure 36-4. Power Supply Regulator

(b) Why does output current at J-1 decrease?

(c) Does the ripple voltage at TP-5 (INCREASE), (DECREASE), or (REMAIN THE SAME)? Why?

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

p. Trouble 7 - Open Voltage Adjust Resistor R-4 (S-10 UP).

NOTE: This trouble causes the voltage between TP-8 and TP-9 to reverse polarity. TP-9 will be negative in respect to TP-8.

(1) Locate this trouble on figure 36-4.

(2) Use the schematic diagram and the recorded measurements to analyze trouble.

(3) Answer the following questions:

(a) What (two) values are different with this trouble than the values obtained with an open Q-2 collector? Why are they different?

(b) The output voltage has the highest value with the R-4 resistor open. Why?

(c) With this trouble, Q-1 is (CONDUCTING NORMALLY) (SATURATED) (CUT OFF).

(d) With this trouble, Q-2 is (CONDUCTING NORMALLY) (SATURATED) (CUT OFF).

CONFIRM YOUR ANSWERS AND REMOVE THE TROUBLE.

ADJUNCT GUIDE

ANSWERS TO A:

1. no output 2. no output
3. no output 4. destroy the diode
5. decrease 6. open filter capacitor
7. half-wave rectifier 8. fuse
9. shorted diode, shorted filter capacitor

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. Zener diode open
2. input voltage, output regulation
3. excessive load current

If you missed ANY questions, review the material before you continue.

LABORATORY EXERCISE 36-1

ANSWERS TO 3c(4) - (OPEN FUSE):

(a) Measurements 2 through 8 were not necessary. With zero volts from TP-3 to TP-4 all other voltages will be zero. Zero volts between TP-3 and TP-4 indicate the trouble must be toward the power source.

(b) If blowing of the fuse were caused by a shorted or malfunctioning component, a replaced fuse would blow. The trouble would not be corrected. The malfunction would have to be corrected before replacing the fuse.

CONCLUSION: When all currents and voltages are zero, the fuse must be open, the OFF-ON switch must be open, or there is no power from the source. for This trainer, a blown fuse causes zero readings of current and voltage at all test points.

ANSWERS TO 3d(4) - (OPEN) TRANSFORMER CENTER TAP):

(a) Voltage at TP-5 was zero. In a half-wave rectifier, current must flow from ground through the load, through Q-1 and L-1, through the diode, and the transformer secondary back to ground. The transformer secondary is no longer grounded so the current path is broken. No voltage will be read at TP-5 or at any point in the EVR.

(b) The ground is open but the transformer secondary coil from TP-3 to TP-4 is NOT, so the secondary voltage will be normal.

(c) Diode CR-2 could also be open with these readings.

CONCLUSION: When there is no output from the rectifier at TP-5, the trouble must be in the rectifier section. Normal voltage at TP-3 and TP-4 further isolates the trouble to the transformer secondary or diode.

ANSWERS TO 3e(4) - (OPEN FILTER CHOKE L-1):

(a) C-1 charges to the peak value of the input. The discharge path for C-1 is open. No discharge current will flow with an open circuit and voltage will be maximum at TP-5.

(b) The coil, L-1, is in series with the current path so no current can flow when it is open. An open coil creates an open circuit.

(c) When L-1 is open, there is no discharge path for C-1, so it will hold the voltage at peak value and show as a straight line on the oscilloscope.

CONCLUSION: If the output current and voltage are zero, an open in the circuit should be suspected. If all readings beyond the choke are zero, this component is likely to be the cause. A very large voltage drop across the filter choke will confirm that it is open.

ANSWERS TO 3f(4) - (SHORTED FILTER CHOKE):

(a) Ripple voltage at TP-5 decreases when L-1 is shorted. Normally, the ripple voltage at TP-5 is determined by the time constant of the discharge of C-1. When L-1 TP-5 is determined by the time constant of the discharge of C-1. When L-1 is is shorted. the ripple voltage at TP-5 is determined by the discharge time of both C-1 and C-2. Capacitors in parallel add so the discharge time will be longer and the ripple voltage will be smaller.
(b) Ripple voltage at TP-6 increases when L-1 is shorted because what was once an efficient pi-type filter becomes a simple capacitive filter.
(c) L-1 has inductance and resistance which lowers the voltage across C-2. When it is shorted, there is less total opposition so the voltage across C-2 becomes higher. The increase in voltage at TP-6 is greater than the EVR can control so the output increases slightly.
CONCLUSION: A shorted filter choke will usually result in a small increase in output voltage with poor regulation. If there is no voltage drop across the choke, it is shorted. The same ripple and DC voltage readings at both TP-5 and TP-6 confirms that the choke is shorted.

ANSWERS TO 3g(4) - (OPEN FILTER CAPACITORS C1 AND C2):

(a) Normally C-1 and C-2 discharge slowly so the voltage never drops all the way to zero. When C-1 and C-2 are open, the voltage does drop to zero and so exhibits a greater peak-to-peak fluctuation on the oscilloscope.
(b) The filter capacitors raise the average voltage at TP-6.
(c) When the voltage drops to zero on each cycle, the average voltage also drops. If this average voltage is less than the normal output, the output voltage of the EVR will be less. The ability of this regulator to regulate has been exceeded.
CONCLUSIONS: The DC output voltage at TP-6 will be greatly reduced if the filter capacitors are open. This will result in low voltage at the output of the EVR (TP-10). A very large increase in the ripple voltage at TP-5 confirms the filter capacitors as the faulty components.

ANSWERS TO 3h(5) - (OPEN LOAD RESISTOR R-8):

(a) Zero. With the load resistor open, there is no path for current to flow.
(b) When the load resistor is open, voltages can be read at all test points. Any other malfunction that causes zero current also causes zero voltage at one or more test points.
(c) Yes, the ripple voltage at TP-5 decreases. C-1 discharges more slowly because resistance increases (longer TC). With the load resistor open, the total resistance increases because the load resistor is in parallel with the other resistors in the EVR.
CONCLUSION: When output current is zero, but output voltage is near normal, the circuit must be functioning properly up to the output. Therefore the faulty component must be the load resistor.

ANSWERS TO 3j(4) - (OPEN T-1 CENTER TAP):

(a) Zero. The voltage at TP-5 is the source for the voltage at TP-10. The voltage at TP-5 was zero. An open center tap opens the circuit for the rectifiers. The output voltage of the transformer will be dropped across the open.
(b) The transformer secondary is not open between these two points.
(c) First, remove all power by disconnecting the trainer power cord from the wall outlet. Second, disconnect one end of CR-1 and CR-2. Then, measure the resistance from TP-3 or TP-4 to GND. An infinite reading would indicate an open.

ANSWERS TO 3k(2) - (OPEN L-1):

(a) C-1 charges to the peak of the input to the diodes CR-1 and CR-2. The discharge path for C-1 is open so C-1 does not discharge between peaks.

ANSWERS TO 3k(2) - Continued

(b) Zero. In a series circuit all of the voltage appears across the open, with zero volts across the good components. In this case all of the voltage appears across L-1, with no voltage across R-1.
(c) C-1 charges to the peak value. Because L-1 is open, C-1 does not discharge between pulses.

ANSWERS TO 31(2) - (SHORTED L-1):

(a) decreased (b) increased
(c) same as
(d) C-2 is allowed to charge to the peak amplitude of the voltage input to the rectifier. Opposition normally offered by the resistance and inductance of L-1 is shorted out.

ANSWERS TO 3m(2) - (OPEN C-1 & C-2):

(a) The DC voltage at TP-5 is the average value while ripple voltage is a peak value. To convert from peak to average for a full-wave rectifier, multiply the peak value by .636. So, 22 V x .63 = 13.86 V.
(b) The filtering effect of L-1 prevents the voltage at TP-6 from dropping to zero between pulses. The ripple voltage is the difference between the highest and lowest points of the waveform. Therefore, the ripple voltage at TP-6 will be less.
(c) A very large ripple reading at TP-5 indicates an open filter capacitor. A shorted L-1 will indicate a much smaller increase in ripple voltage.

ANSWERS TO 3n(3) - (OPEN COLLECTOR Q-2):

(a) Approximately 10 volts. This should be equal to the value of TP-5 to TP-8 plus TP-8 to TP-12.
(b) The collector voltage on Q-2 with the collector open is maximum, just as it would be with Q-2 cut off. This means that the voltage on the base of Q-1 is also maximum. Q-1 is in saturation and all of the voltage is dropped by the load circuit. Therefore the output voltage is high and unregulated.
(c) The ripple voltage at TP-5 is higher because C-1 discharges more rapidly when Q-1 is saturated (very low resistance).

CONCLUSION: High output current and voltage means that Q-1 is conducting hard and may be in saturation. Unless Q-1 is shorted, the bias and base voltage must be high. The probable cause of this is an open or cutoff Q-2. If forward bias on Q-2 is near normal, it is likely that the collector of Q-2 is open.

ANSWERS TO 3o(3) - (BYPASSED ZENER DIODE CR-3):

(a) A bypassed Zener diode CR-3 allows more current to flow through Q-2 because the resistance is less. More current through the collector of Q-2 means less voltage at the collector and therefore less voltage on the base of Q-1 causing Q-1 to conduct less. The output voltage will decrease.
(b) The decrease in output voltage causes a decrease in current through the load.
(c) The ripple voltage at TP-5 will decrease because the increase in total resistance will cause C-1 to discharge more slowly (increased TC). When C-1 discharges slowly, the voltage does not go as low so the ripple value decreases.
CONCLUSION: Low output current and voltage may be caused by a shorted Zener diode. If little or no voltage can be measured across the Zener diode, the trouble will be isolated to that component. This trainer has a small resistor in the shorting circuit. This is the reason why a small voltage is measured when the Zener is shorted instead of zero voltage.

ANSWERS TO 3p(3) - (OPEN VOLTAGE ADJUST R-4):

(a) Bias and Control Voltage. The open is between the base of Q-2 and V_{CC}. The base of Q-2 is connected to ground through R-4 and R-5. With no current flowing, the base will be at ground potential. Therefore the control voltage, which is from ground to the base of Q-2, will be zero. There is a positive voltage on the emitter of Q-2 so there will be reverse bias from emitter to base.

ANSWERS TO 3p(3) - Continued

(b) Normally R-3, R-4, and R-5 are in parallel with the load resistors R-7 and R-8 and draw some current. This current causes a drop in output voltage. With R-4 open, the path through R-4 is open and almost all of the voltage is dropped across the load resistors. (There is a small voltage drop caused by current through R-2 and R-6.) When Q-2 collector is open, the current through R-3, R-4, and R-5 will drop some voltage so the voltage across the load resistor will not be as great.

(c) Q-1 is saturated.

(d) Q-2 is cut off.

CONCLUSION: When the output voltage and current are much higher than normal, Q-2 is probably open or cut off. An open R-4 between the base of Q-2 and V_{CC} will cause reverse bias on Q-2 which will put it in cutoff. An open R-3 will give the same symptoms.

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

ATC HO 3AQR3X020-X
Prepared by Keesler TTC
KEP-HO-18

Technical Training

Electronic Principles (Modular Self-Paced)

Module 36

TROUBLESHOOTING SOLID STATE POWER SUPPLIES

December 1975

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

ATC Keesler 6-2800

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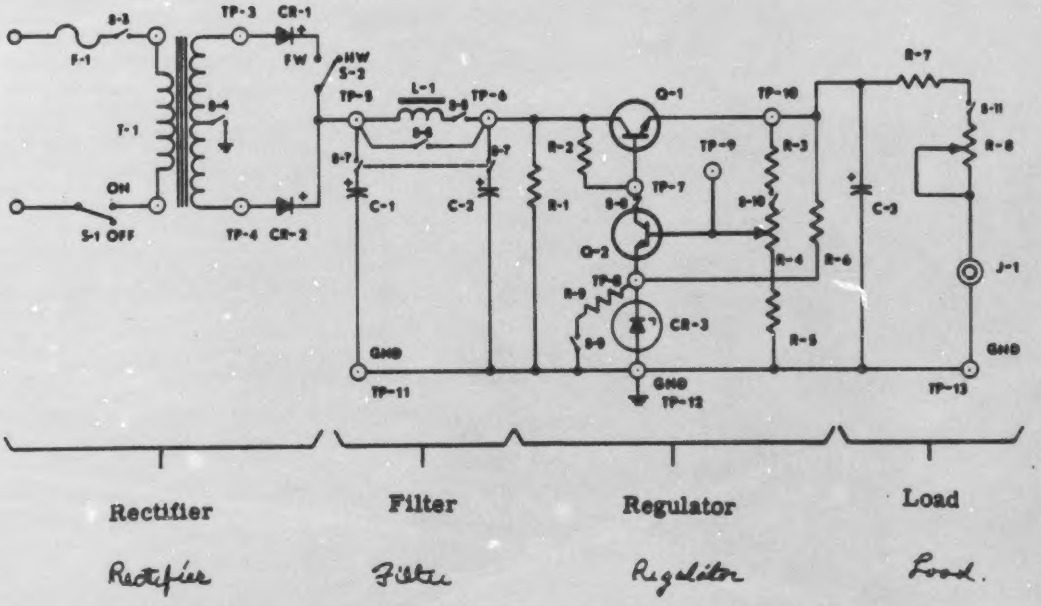

S-3
F-1
T-1
S-4
ON
S-1 OFF
TP-3
CR-1
FW
HW
S-2
TP-4
CR-2
TP-5
L-1
S-5
TP-6
S-6
S-7
S-7
C-1
C-2
GND
TP-11
R-1
R-2
Q-1
TP-7
S-8
Q-2
TP-8
R-9
S-9
CR-3
GND
TP-12
TP-9
TP-10
R-3
S-10
R-4
R-6
R-5
C-3
R-7
S-11
R-8
J-1
GND
TP-13
Rectifier
Filter
Regulator
Load
Rectifier
Filter
Regulator
Load.

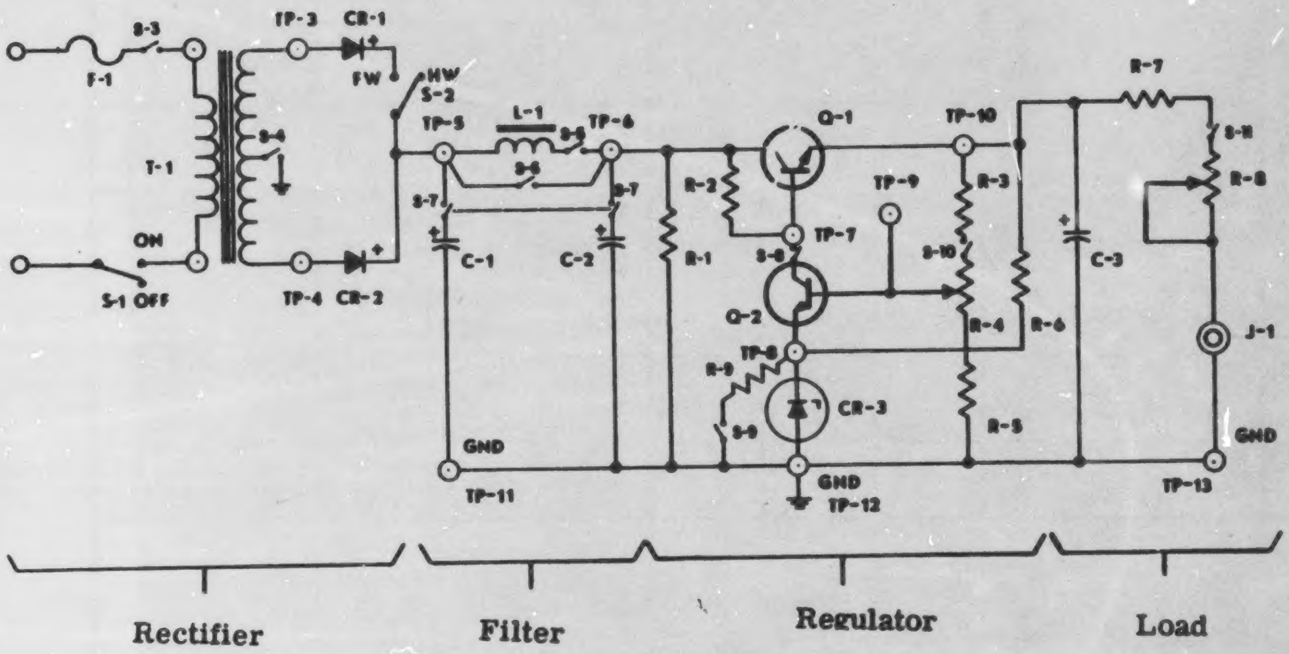
Figure 1. Power Supply Troubleshooting Trainer

HALF-WAVE RECTIFIER POWER SUPPLY

Measurement Points	Nominal Values	Normal Measured	1 Open Fuse S-3	2 Open T-1 CT S-3	3 Open L-1 S-5	4 Short L-1 S-6	5 Open C-1, C-2 S-7	6 Open R-8 S-11
	Exercise							
1. Secondary Voltage (AC) TP-3 to TP-4	30							
2. Rectified Voltage (DC) TP-5 to GND	19							
3. Ripple Voltage (Pk-Pk) TP-5 to GND (Scope)	.46							
4. Filtered Voltage (DC) TP-6 to GND	16							
5. Filtered Ripple Voltage (Pk-Pk) TP-6 to GND (Scope)	0							
6. Voltage dropped by Choke L1 TP-5 to TP-6	3.2							
7. Output Voltage TP-10 to GND	5							
8. Output Current J-1	2							

Chart 1. Troubleshooting Summary Chart

Figure 1. Power Supply Troubleshooting Trainer


S-3
TP-3
CR-1
F-1
FW
HW
S-2
T-1
S-4
ON
S-1 OFF
TP-4
CR-2
TP-5
L-1
S-5
TP-6
S-6
S-7
C-1
C-2
R-1
R-2
Q-1
TP-7
S-8
Q-2
TP-8
R-9
S-9
CR-3
TP-9
TP-10
R-3
S-10
R-4
R-5
R-6
C-3
R-7
S-11
R-8
J-1
GND
TP-11
GND
TP-12
TP-13
GND
Rectifier
Filter
Regulator
Load

Power Supply Troubleshooting Trainer

FULL-WAVE RECTIFIER POWER SUPPLY

Measurement Points	Exercise								
	Nominal Values	Normal Measured	Open T-1 CT S-4 1	Open L-1 S-5 2	Short L-1 S-6 3	Open C-1, C-2 S-7 4	Open Q-2 Coll. S-8 5	Bypassed Zener S-9 6	Open R-4 S-10 7
1. Secondary Voltage (AC) TP-3 to TP-4	30								
2. Rectified Voltage (DC) TP-5 to GND	20								
3. Ripple Voltage (Pk-Pk) TP-5 to GND (Scope)	.23								
4. Filtered Voltage (DC) TP-6 to GND	165								
5. Filtered Ripple Voltage (Pk-Pk) TP-6 to GND (Scope)	0								
6. Voltage dropped by Choke L1 TP-5 to TP-6	3.4								
7. Voltage dropped by Q-2 TP-7 to TP-8	3.1								
8. Biasing Voltage for Q-2 TP-8 to TP-9	.6								
9. Reference Voltage TP-8 to GND	2.4								
10. Control Voltage TP-9 to GND	3								
11. Output Voltage TP-10 to GND	5								
12. Output Current J-1 (MA)	2								

Chart 2. Troubleshooting Summary Chart

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PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-37

Technical Training

ELECTRONIC PRINCIPLES

MODULE 37

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

1 August 1974

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

Guidance Package 3AQR30020
KEP-GP-37
1 August 1974

ELECTRONIC PRINCIPLES

MODULE 37

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

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Overview	1
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Digest	3
Adjunct Guide	7
Laboratory Exercise	13
Module Self-Check	22
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Supersedes KEP-GP-37, 1 November 1973. Supplies on hand will be used.

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

1. SCOPE: Power amplifiers are usually the final stages of an amplifier circuit or component. They add to the AC intelligence signal the power necessary to drive loads, such as speakers, headphones, and scopes. There are several configurations of these amplifiers. Here we discuss the push-pull, complementary-symmetry, and compound-connected amplifiers. In addition, we cover the paraphase amplifier and troubleshoot the push-pull amplifier.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives:

a. Given a list of statements, select the one which describes the effect of changing forward bias on push-pull amplifier

(1) class of operation.

(2) crossover distortion.

(3) efficiency.

b. Given the schematic diagram of a single-stage paraphase amplifier, determine

(1) DC current path.
(2) output signal.
(3) voltage gain.

c. Given the schematic diagram for a complementary-symmetry circuit using a common collector configuration, determine

(1) DC current paths.
(2) input signal requirements.
(3) output signals.
(4) source polarities.

d. Given a schematic diagram for a compound-connected power amplifier using a common base configuration, determine the

(1) DC current paths.

(2) current gain.

e. Given a trainer having an inoperative transistor push-pull power amplifier, schematic diagram, multimeter, and oscilloscope, determine the faulty component.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following.

READING MATERIALS:

Digest

Adjunct Guide with student Text

LABORATORY EXERCISE:

Laboratory Exercise 37-1, Solid State Power Amplifiers

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

The last stage of a series of amplifiers is usually the power amplifier. Power amplifiers are designed to achieve maximum power gain. Transistors working at high power levels have certain limitations. One of these is the amount of power it can dissipate. The maximum power dissipation (PD_{MAX}) rating of a transistor is the maximum power it can dissipate without danger of being destroyed. Figure 1 shows a PD_{MAX} curve for a type 2N2067 transistor. Notice that at any point on the curve the product of $V_C I_C$ is 5 watts. The transistor must not be operated to exceed 5 watts of collector dissipation. Another limitation of transistors working at high power levels is the heat generated internally. Transistors become unstable as junction temperature increases. Heat sinks, in the form of cooling fins, are used to move heat away from the junctions.

One commonly used power amplifier is the double-ended or PUSH-PULL amplifier. Figure 2 shows a push-pull power amplifier. The circuit is forward biased through R1 and the two halves of the center-tapped secondary of T1. As shown, the circuit operates class A, but for better efficiency, it can be operated class B. If the center tap is grounded rather than returned to V_{CC} through R1, the circuit will operate class B. The secondary of T1 is center-tapped to provide two signals 180° out of phase but equal in amplitude to the bases of Q1

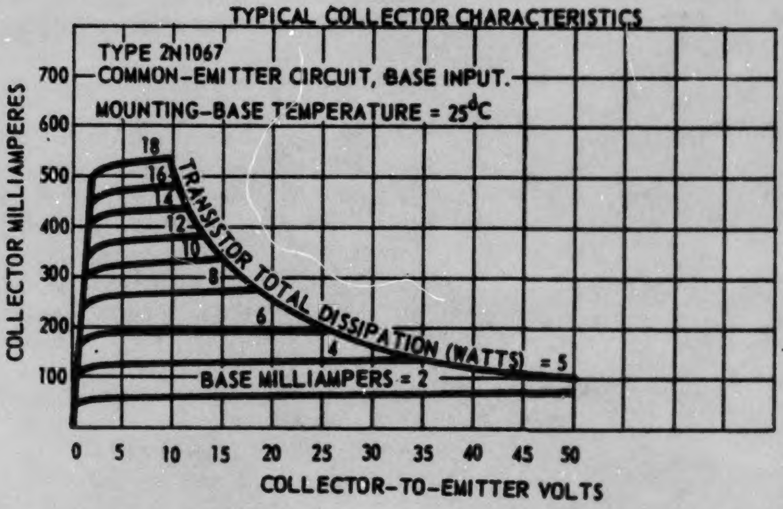


Figure 1. Power Dissipation Curve for 2N1067 Transistor, PD_{MAX}

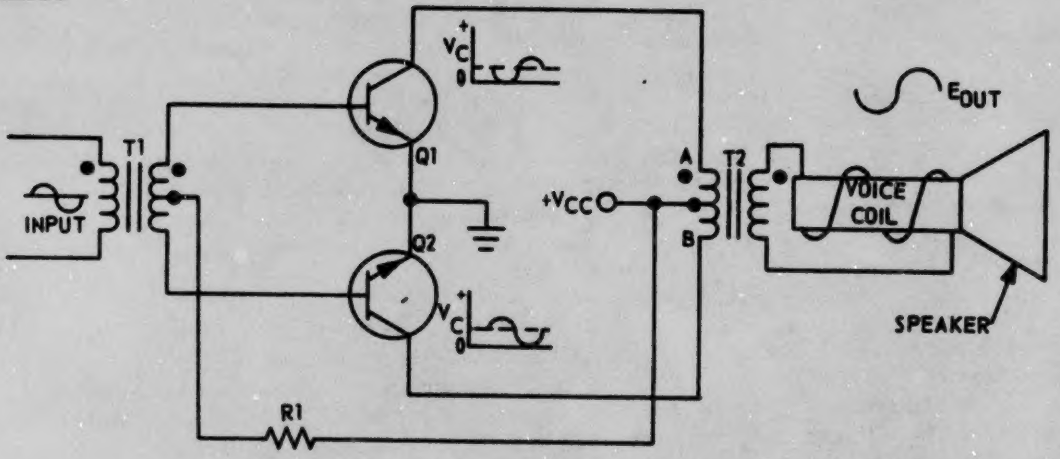


Figure 2. Class A, Push-Pull Power Amplifier

and Q2. The out of phase signals cause Q1 to conduct on one alternation of the input and Q2 on the other. The primary of output transformer T2 is also center-tapped. The top half of the primary of T2 is the collector lead for Q1. On the alternation when Q1 conducts, the changing current in the top half of the primary induces a current in the secondary and one alternation is reproduced. On the other alternation, Q2 conducts through the bottom half of the primary, reproducing the other alternation at the output. It can be said that T2 recombines the signals which were split at the secondary of T1. If Q1 and Q2 are balanced, all even harmonics are cancelled. Balancing can be done by putting a variable resistance in the circuit which is common to the emitters of Q1 and Q2. The power output of a push-pull amplifier can be MORE than twice that of a single-ended power amplifier. When a push-pull amplifier is operated at any class except A, it is subject to a type of distortion called CROSS-OVER distortion. Figure 3 shows an example of cross-over distortion in a push-pull amplifier. This type of distortion is due to the fact that the SIGNAL provides the forward bias for the transistors. When the signal decreases in amplitude, the transistor is brought into the low forward bias area of its curve and distortion occurs. As the signal on the base of Q1 decreases in amplitude, distortion occurs and as Q2 starts to conduct, the low amplitude signal and forward bias causes distortion. The distortion always occurs at the point where one transistor is going off and the other on, thus, the name CROSS-OVER distortion. Cross-over distortion can be eliminated or reduced by applying a small DC forward bias or by operating class AB.

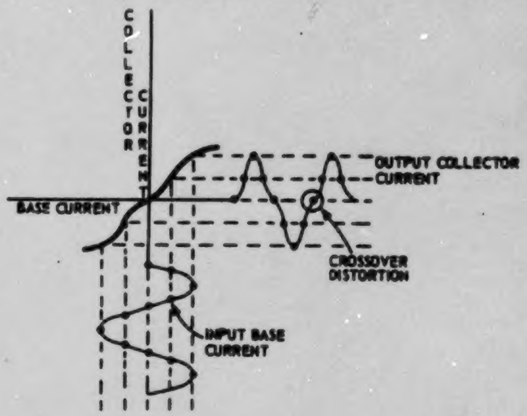
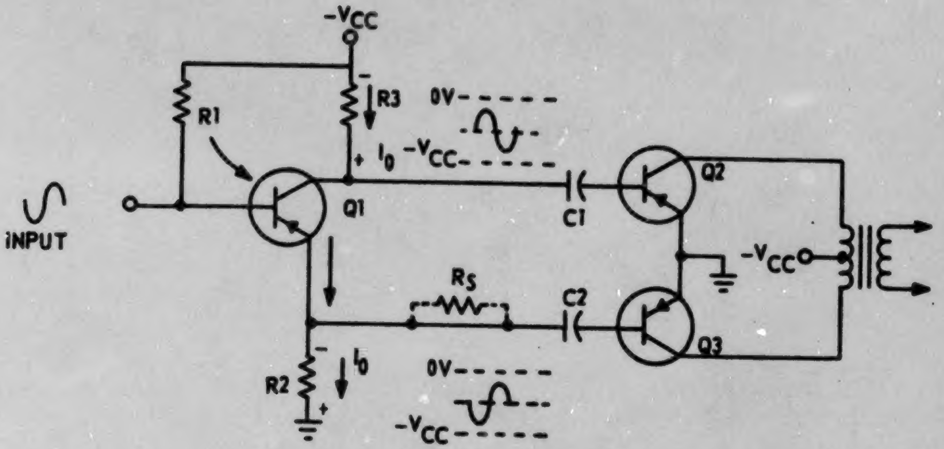


Figure 3. Class B Push-Pull Waveforms (Cross-Over Distortion

We mentioned earlier that the input transformer of a push-pull amplifier splits the signal into two halves which are equal in amplitude and 180° out of phase. An electronics circuit which will accomplish this is the paraphase amplifier or phase SPLITTER.



REP4-676

Figure 4. One-Stage Phase Splitter

Figure 4 shows a paraphase amplifier connected to a push-pull amplifier.

The signals at the emitter and collector of Q1 are 180° out of phase and will be equal in amplitude at the bases of Q2 and Q3. R_S increases the low emitter output impedance of Q1 to match the higher collector impedance. Q2 and Q3 in figure 4 are operated Class B. Forward bias is provided by the signal, which is coupled by C1 and C2. On the alternations that Q2 and Q3 are off, the coupling capacitors have no discharge path except through the reverse biased base-to-emitter junctions. This causes the transistor to operate Class C. If a diode is connected between the base of each transistor and ground, a discharge path is provided. These are called discharge diodes. The voltage gain of a paraphase amplifier is less than one. The low gain causes the bandpass to be greater. The frequency response of this circuit is much better than that of a center tapped transformer.

A circuit similar to the push-pull amplifier but without the need of either an input transformer or phase-splitter is the complementary-symmetry amplifier shown in figure 5. The circuit does not need out of phase signals because QI is a PNP transistor and Q2 is a NPN. The signal is applied to both bases through balance resistor R3. When the signal goes positive, both bases go positive. A positive on the base of Q1 causes it to decrease in conduction but causes Q2 to increase. Q2 conducts from ground through R_L, Q2, to V_{CC2}, reproducing the positive alternation across R_L. Q1 conducts from V_{CC1}, Q1, through R_L to ground, reproducing the negative alternation across R_L. The load, R_L, might be the voice coil of a speaker rather than a resistor as shown. Notice that two batteries are used so as to apply the correct polarity of V_{CC} to the two transistors. When an electronic power

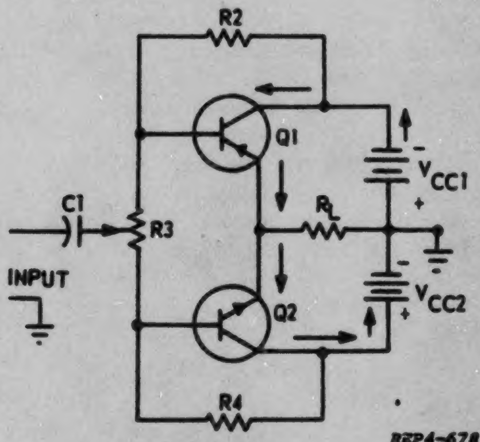


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Figure 5. Complementary-Symmetry Circuit

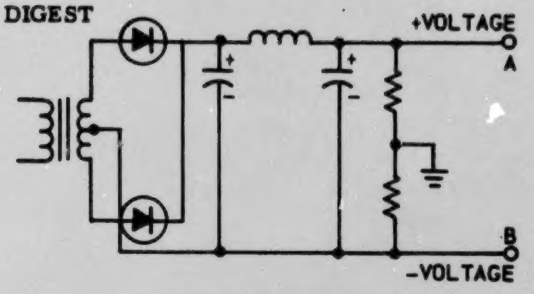

Figure 6. Power Supply for a Complementary-Symmetry Amplifier

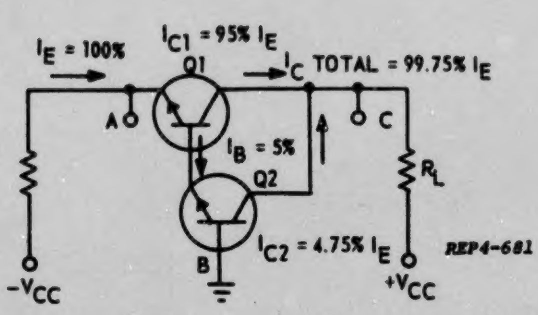

Figure 7. Compound-Connected Common Base

supply is used, both positive and negative voltages can be obtained from the same power supply. A common method of doing this is shown in figure 6.

The current, voltage, and power gains of a common base amplifier are directly related to the forward current transfer ratio (alpha). This is the ratio of I_C to I_E and the greater this ratio, the greater the current gain. A circuit which is designed to increase alpha is the COMPOUND-CONNECTED amplifier shown in figure 7. Q1 and Q2 are both connected in common base configuration.

Notice that the base current of Q1 is the emitter or input current of Q2. Notice also that the two collector currents add in R_L. Assume each transistor has an alpha of .95 and that the input current to Q1 is 10 mA. Since alpha is .95, I_C for Q1 is 9.5 mA. Base current for Q1 is therefore, .5 mA. Input or emitter current for Q2 is also .5 mA. Alpha of Q2 is also .95, so I_C for Q2 is .475 mA. I_T is $I_{CQ1} + I_{CQ2}$ or 9.975 mA. Alpha for the circuits is $\frac{9.975 \text{ mA}}{10 \text{ mA}}$ or .9975, which is a considerable increase over .95.

Figure 8 shows a push-pull amplifier. R3 is a balancing resistor and the transistors are forward biased by R1 and R2. C1 places the center tap of the transformer at AC ground. In troubleshooting this circuit, the things to look for are presence and amplitude of output signal, cross-over distortion, and presence and amplitude of DC voltages. For example, if the primary of T1 or secondary of T2 open, all DC voltage would be normal but there would be no output signal. If the secondary of T1 or primary of T2 open, one of the transistors would be off and the output weak and distorted. If R1 and C1 shorts or R2 opens, the transistors would operate class B and cross-over distortion would be present. Should R1 open, the forward bias would increase. V_C would be low on both transistors, the output would be larger than normal and possibly distorted. C1 open would cause degeneration and the output would be smaller than normal but all DC voltages would be normal. Shorting R2 would place V_{CC} on the base leads. This would cause excessive forward bias and possibly a blown fuse and/or destruction of the transistor. If the wiper arm of R3 opened, both transistors would cut off. There would be no output signal and V_C on Q1 and Q2 would equal V_{CC}.

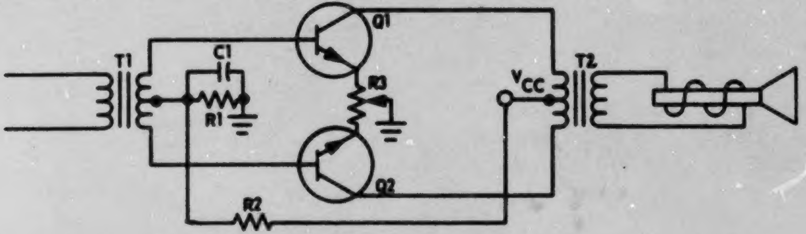

Figure 8

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF CHECK.

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

INSTRUCTIONS:

Study the referenced material as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

Any signal that is generated or received for some useful purpose is usually small in its original form and must be increased to a sufficient power level to perform some useful work. Such signals could be related to those received from a phonograph pickup or radio frequency signals received by a radio or television set.

These small signals may be sent through several stages of amplifier circuits to increase the signal level. However, the last stage, or output stage, is designed to amplify the signal to the power level needed to perform the useful work. This last stage is called the power amplifier stage and may be one, or a combination of, several different types of circuits.

The most commonly used circuit for this purpose is the push-pull power amplifier. In this module you will study the various types of power amplifier circuits and the classes of operation. Also, you will learn how to troubleshoot and repair them when malfunctions occur.

Study this material very carefully for you will find a power amplifier stage in nearly every functional piece of equipment that you encounter.

A. Turn to Student Text, Volume V, and read paragraphs 5-1 through 5-9. Return to this page and answer the following questions.

1. Where intermediate amplifier stages are designed to obtain maximum voltage or current gain, the power amplifier stage is designed to obtain maximum ____________________.

2. What is the main disadvantage of using a single transistor in a power amplifier stage?

____.

3. The product of the DC quantities of V_{CE} and I_C of a transistor is known as the

________________________________.

ADJUNCT GUIDE

4. Given a transistor with a 3 watt PD_{MAX} rating in a circuit with V_{CE} = 10 volts and I_C = 200 milliamps, the transistor would exceed the PD_{MAX} and burn up. (TRUE) (FALSE)

5. Under AC conditions the instantaneous values of voltage and current may exceed the PD_{MAX} rating as long as the average power does not. (TRUE) (FALSE)

6. On a given transistor characteristic curve chart, the power dissipation curve shows

______________________________________.

7. The load line and operating point must always be to the ________________________ of the maximum power dissipation curve on the characteristic curve chart.

8. What device is used to dissipate heat away from the transistor junctions?

9. What effect does high junction temperatures have on the stability of a transistor?

10. Power amplifier stages have __________________ values of load impedance than preceding stages.

CONFIRM YOUR ANSWER ON THE NEXT EVEN NUMBERED PAGE.

B. Turn to Student Text, Volume V, and read paragraphs 5-10 through 5-30. Return to this page and answer the following questions.

1. A push-pull amplifier contains two transistors which operate in a _______________ degree phase relationship.

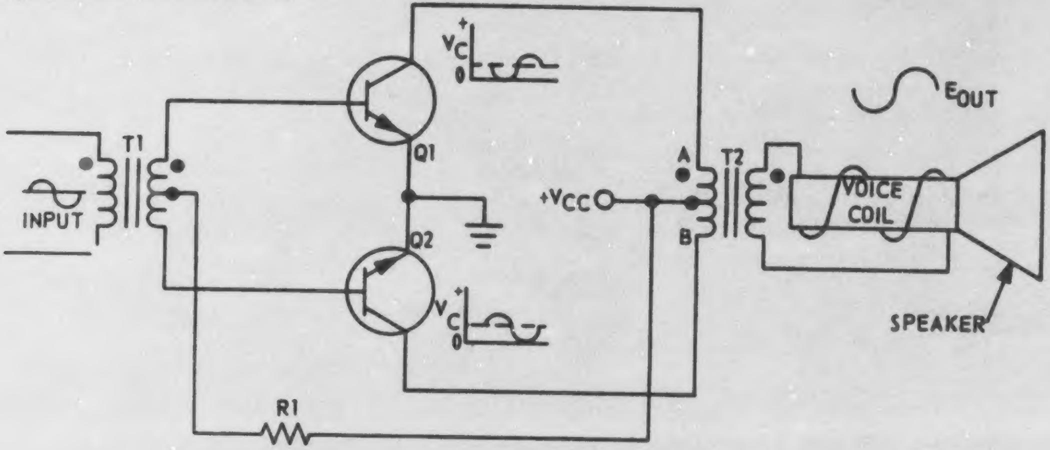

Figure 1. Class A, Push-Pull Power Amplifier

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2. What is the purpose of R1 in figure 1?

3. What is the primary disadvantage of a Class A push-pull power amplifier?__________ ____________________.

4. What is the primary advantage of a Class A push-pull power amplifier?__________ ____________________.

5. Referring to figure 1, what is the voltage relationship between point A and point B with no input signal applied to Q1 and Q2? ____________________.

6. Referring to figure 1, the positive alternation of the input signal will cause the conduction of Q1 to __________ and Q2 to __________.

7. The power output from a Class A push-pull amplifier can be more than __________ that obtainable from a single-ended class A power amplifier.

8. All __________ harmonics are cancelled in a Class A push-pull power amplifier.

9. What is the advantage of a class B push-pull amplifier over a Class A push-pull amplifier? ____________________

10. How can a Class B push-pull amplifier circuit be identified from a Class A push-pull amplifier circuit? ____________________

11. With no input signal present to a Class B push-pull amplifier, both transistors are ____________________.

12. What is the primary disadvantage of a Class B push-pull amplifier?__________ ____________________

13. At what point in the collector current output waveform does the most severe distortion occur in a Class B push-pull amplifier? ____________________

14. How can crossover distortion be eliminated or reduced in a Class B push-pull amplifier? ____________________

15. By applying a small amount of forward bias to both transistors in a Class B push-pull amplifier, the class of operation will change to ____________________.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ADJUNCT GUIDE

ANSWERS TO A:

1. power
2. limited maximum power dissipation
3. PD_{MAX} - maximum power dissipation
4. False
5. True
6. Maximum I_C for any value of V_{CE}
7. left
8. heat sink
9. stability decreases
10. smaller

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. 180°
2. provide forward bias for Q1 and Q2
3. low efficiency
4. minimum distortion
5. equal
6. increase, decrease
7. twice
8. even
9. greater efficiency
10. by the lack of a forward biasing network
11. cutoff
12. greater output distortion
13. cross-over
14. by applying a small forward bias on both transistors
15. Class AB

If you missed ANY questions, review the material before you continue.

C. Turn to Student Text, Volume V, and read paragraphs 5-31 through 5-50. Return to this page and answer the following questions.

1. The term used to describe the amplifier which is used to supply the signal input to the power amplifier stage is ______________________________.

2. What component would be eliminated by using a phase splitter circuit to drive the push-pull power amplifier in figure 1? ______________________________.

3. When compared to center-tapped transformer, the frequency response of the phase-splitter amplifier is ______________________________.

4. The reason for adding series resistor R_S in figure 2 is to ____________________

____.

5. How is the loss of signal voltage across R_S compensated in the circuit in figure 2?

____.

6. How is the charge and discharge time of the coupling capacitors equalized in a Class B push-pull amplifier? ____.

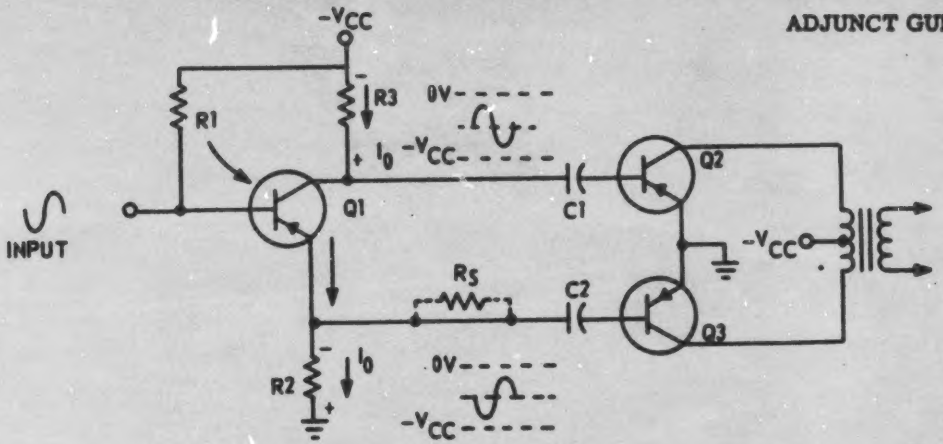

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Figure 2. One-Stage Phase Splitter

7. The circuit that provides the advantages of a conventional push-pull amplifier without the need of a phase-inverter stage or center-tapped transformer is called a ________________ ________________________ circuit.

8. A complementary-symmetry circuit requires ______________________ input signal.

9. In a complementary-symmetry circuit, the amount of current flow depends upon the ____ of the incoming signal.

10. The direction of current flow through the load resistor of a complementary-symmetry circuit depends on the __________________ of the incoming signal.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

D. Turn to Student Text, Volume V, and read paragraphs 5-51 through 5-61. Return to this page and answer the following questions.

1. A compound-connected amplifier is a circuit designed to increase ______________.

2. Compound-connected transistors in a circuit of any configuration can be considered as a ________________________________.

3. In a compound-connected amplifier, the total current through the load is equal to the collector current of both transistors. (TRUE) (FALSE)

4. Referring to figure 1, what would be the effect on the circuit if R1 were open?

____

____

5. Referring to figure 1, if Q1 opened, there would be no output from the circuit. (TRUE) (FALSE)

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ANSWERS TO C:

1. driver stage
2. coupling transformer T-1
3. wider
4. balance output impedance
5. increasing R2 to a higher value than R3
6. by using discharge diodes
7. complementary-symmetry
8. one
9. magnitude
10. polarity

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1. alpha
2. single unit
3. True
4. no forward bias voltage
5. False

If you missed ANY questions, review the material before you continue.

E. Turn to Laboratory Exercise 37-1 and complete all sections before returning to this page. The material in this exercise is arranged to give you practical experience in troubleshooting analysis of malfunctioning power amplifiers similar to those you will encounter in the field. If you have any difficulty, contact your instructor.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

OBJECTIVES:

1. Given a push-pull power amplifier trainer, oscilloscope, multimeter, signal generator, and schematic diagram, measure the signal input and output amplitudes of each transistor and determine the effect of varying bias voltage.

2. Given an inoperative push-pull power amplifier trainer, schematic diagram, multimeter, signal generator, and oscilloscope, determine the faulty components, two out of three times.

Upon completion of this exercise have your instructor initial these objectives on your progress check.

EQUIPMENT:

1. Transistor Push-Pull Amplifier, Trainer #5969.
2. Transistor Power Supply, Trainer #4649.
3. Oscilloscope (LA-261).
4. Multimeter (PSM-6).
5. Signal Generator, Trainer #4864.

REFERENCES:

Student Text, Volume V, Chapter 5.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Analysis of the trainer.
   a. The transistor push-pull amplifier trainer schematic is shown in figure 37-1.
   b. The trainer requires a signal input from a signal generator to produce an output.
   c. The trainer incorporates rheostat R5 for changing forward bias.
2. Preparation of the equipment:

a. Oscilloscope Controls (LA-261)	Position
(1) POWER	ON
(2) VOLTS/DIV	A Channel .5 Calibrated

LABORATORY EXERCISE 37-1

a. (Continued)

Oscilloscope Controls (LA-261)	Position
(3) VOLTS/DIV	B Channel .5 Calibrated
(4) MODE	Alternate
(5) A & B CHANNEL POLARITY	Normal AC
(6) TRIGGER SELECTOR	EXT +
(7) MODE	AUTO
(8) HORIZONTAL DISPLAY	NORMAL
(9) TIME/DIV	.5 millisec. Calibrated

b. Signal Generator Controls (#4864)	Position
(1) POWER	ON
(2) SINE WAVE AMPLITUDE	MINIMUM
(3) SINE WAVE RANGE	1 Volt
(4) FREQUENCY MULTIPLIER	10
(5) FREQUENCY (Hz)	100

c. Trainer, #5969	Position
R5	Fully Counterclockwise
S-7	Left

d. Signal Generator to Trainer

(1) Ground signal generator to trainer at TP102.

(2) Connect output of signal generator to trainer at TP101.

e. Oscilloscope to Trainer

(1) Ground oscilloscope to trainer at TP2.

(2) Connect A Channel input to TP1. (Use regular probe).

(3) Connect B Channel input to TP5. (Use regular probe).

(4) Connect trigger input to TP8.

(5) Position the A Channel sweep the upper section of the oscilloscope display.

(6) Position the B Channel sweep to the lower section of the oscilloscope display.

f. Power Supply to Trainer

(1) Connect the power supply to the trainer with the power cable provided.

(2) Set power supply voltage output (V_{CC}) to 9 volts by using the meter and adjustment on the power supply and re-check voltage output using the multimeter at TP110 and ground. Readjust the power supply output voltage as necessary.

3. Activity

a. Adjust the sine wave input amplitude for 2 volts peak-to-peak.

(1) Adjust the amplitude control on the signal generator to obtain the proper voltage.

(2) Observe Channel A on the oscilloscope to insure a 2 volt peak-to-peak signal amplitude.

b. Measure and compare the amplitude and phase relationship of the input signals to Q1 and Q2.

(1) Move Channel A probe to TP4 and measure the signal amplitude on the base of Q1.

________Volts Pk/Pk.

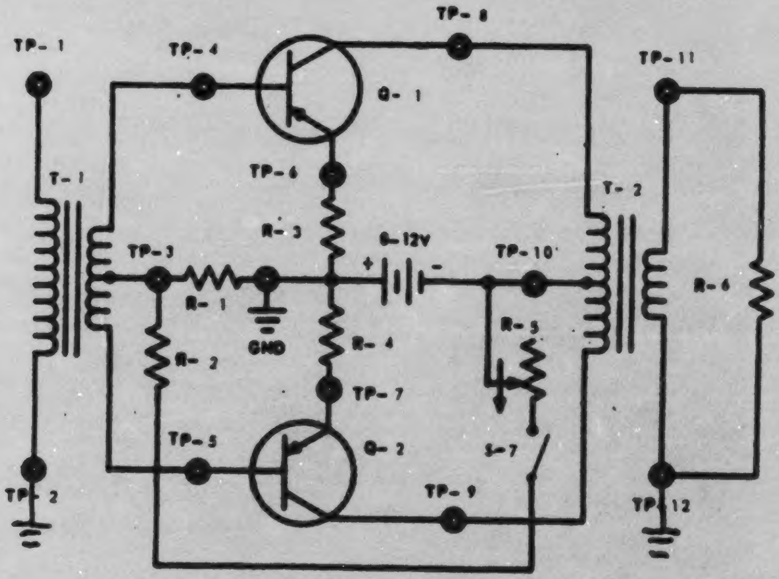


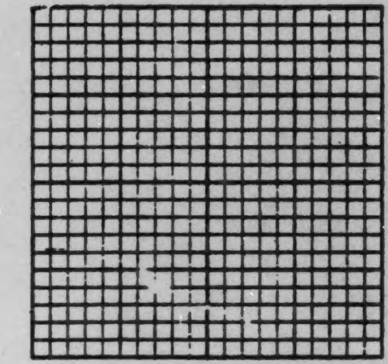
Figure 37-1. Transistor Push-Pull Amplifier

LABORATORY EXERCISE 37-1

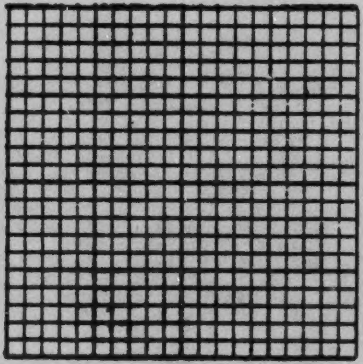
(2) Observe Channel B display and measure the signal amplitude on the base of Q102.

________ Volts Pk/Pk.

(3) Draw the two signal waveshapes on graph A, indicating signal amplitude and phase relationship.



Graph A



Graph B

c. Compare the base and emitter waveshapes of Q1

(1) Connect the Channel B probe to TP6.

(2) Observe and draw the emitter waveshape of Q1. on graph B.

(3) Observe and draw the base waveshape of Q1.

(4) By comparison of the two signals it is evident that:

(a) The negative alternation of the input signal causes Q1 to ____________.

(b) The flat portion of the emitter signal indicates ____________________.

d. Determine the cutoff and conduction time of Q1 and Q2.

(1) Connect Channel B probe to TP7 (emitter of Q2).

(2) Connect Channel A probe to TP6 (emitter of Q1).

(3) Observe the emitter waveshapes of both transistors and calculate the cutoff and conduction time of each.

(a) Q1: Cutoff time ________________ milliseconds

Conduction time ____________ milliseconds

(b) Q2: Cutoff time ________________ milliseconds

Conduction time ____________ milliseconds

(c) The transistors are ____________ longer than they are __________.

(d) The transistors are operating class ________.

e. Determine the effect of the input waveform on bias.

(1) Set the PSM-6 on the 20 k ohm/volt function and the .5 range.

(2) Measure the bias voltage between the base and emitter of Q1: ______ volts.

(3) While measuring the bias voltage on Q1, decrease the input signal amplitude to 0 volts and observe the results. ____________.

(4) Measure the voltage at TP3: _____________.

(5) Measure the bias voltage between the base and emitter of Q2: ______ volts.

(6) While measuring the bias voltage on Q2, increase the input signal amplitude and observe the results. _______________.

CONSULT YOUR INSTRUCTOR FOR VERIFICATION OF YOUR ANSWERS.

NOTE: With R5 fully clockwise there is no forward bias being provided by the voltage divider network. The input signal is causing the emitter-base junction to have reverse bias.

(7) What was the effect on the reverse bias when the input signal amplitude was decreased to 0 volts? ________________.

(8) What was the effect on the reverse bias when the input signal amplitude was increased? ___________________________.

(9) Connect the Channel A probe to TTP1 and adjust the input signal amplitude for 2 volts.

(10) Connect the PSM-6 to TP5 (NEG) and TP7 (POS) and rotate R5 clockwise while observing the PSM-6.

(11) Record the forward bias voltage on Q1 and Q2 with R5 fully clockwise.

(a) V_{EB} Q1: __________ volts.

(b) V_{DB} Q2: __________ volts.

(12) Measure the voltage at TP3: ____________.

(13) What effect did rotating R5 clockwise have on the forward bias voltage?

______________________________________.

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(14) With R5 fully clockwise, the transistors are operating class ________.

f. Determine the effect on the output waveform when bias is varied.

(1) Remove the PSM-6 and rotate R5 fully counterclockwise.

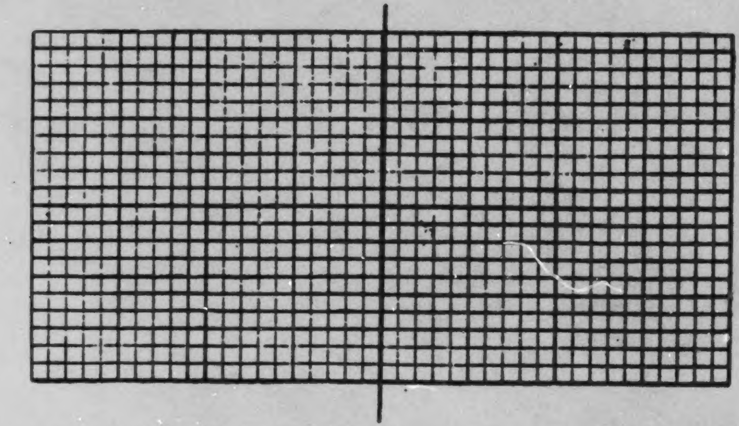
(2) Change the trigger input probe to TP11 and connect Channel A probe to TP8 and Channel B probe to TP9.

(3) Set the oscilloscope VOLTS/DIV control to 5 and measure:

(a) Q1 collector signal voltage: ________ V Pk/Pk.

(b) Q2 collector signal voltage: ________ V Pk/Pk.

(4) Draw the collector waveshapes of Q1 and Q2, showing voltage amplitude (Pk/Pk) and phase relationship on graph C.



Graph C Graph D

(5) Rotate R5 fully clockwise and measure:

(a) Q1 collector signal voltage: ________ V Pk/Pk.

(b) Q2 collector signal voltage: ________ V Pk/Pk.

(6) Draw the collector waveshapes of Q1 and Q2, showing voltage amplitude (Pk/Pk) and phase relationship with R5 fully clockwise on graph D.

(7) What effect does R5 in the fully clockwise position have on the collector signal crossover? ____.

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

5. ACTIVITY

The remainder of this practical exercise is devoted to troubleshooting analysis of the problems inserted within the trainer which will make it inoperative or function abnormally.

This laboratory exercise will provide practice in associating symptoms of a malfunction to a specific trouble and will be conducted in the following sequence.

a. The normal voltage and waveshape measurements will be taken and recorded on the troubleshooting summary chart 37-3.

b. A known trouble will then be placed in the trainer and voltage and wave shape measurements will be taken and recorded in the appropriate blocks on figure 37-3. Compare your readings to the readings on figure 37-2. If any large differences exist, call your instructor.

c. Next you will be questioned to assure association of the abnormal readings to the inserted trouble.

d. This procedure will be repeated for all six troubles.

e. Note: before beginning the exercise detach figure 37-3 and 37-4 from the rear of the guidance package. Figure 37-4 illustrates the location of the switches that simulate the six troubles that can be inserted in the trainer, and figure 37-3 is the troubleshooting summary.

f. Follow the procedures used in setting up the trainer and test equipment that you used in the first section of this laboratory exercise. Be sure to adjust your input (V_{CC} to 9 V. And your input wave form to 2 V Pk/Pk.

5. The first trouble will be R-1 open. On the back of the trainer you will find a panel. Open the panel and place S-1 in the up position.

a. What is the purpose of R1?

b. Using the scope, place "A" channel probe in TP11. Measure and record the Pk/Pk. amplitude of the signal on figure 37-3.

c. Using the PSM-6 place the black lead in TP4 and the red lead in TP6. Record the reading in the appropriate block on figure 37-3.

d. What effect did the trouble have on the signal at TP11?

e. How was the bias on Q1 affected?

6. Next trouble will be R-3 open. (S-2 up and S-1 down).

a. What is the purpose of R-3?

b. What effect would opening R-3 have on the output signal?

c. With the scope measure and record the Pk/Pk amplitude and signal at TP11 in the appropriate block on figure 37-3.

LABORATORY EXERCISE 37-1

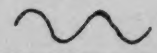
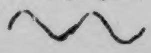
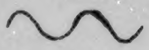
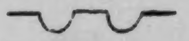
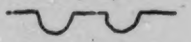
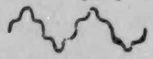
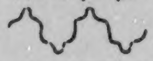
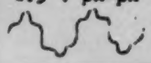
TP1 Input Signal (O'scope)	2 V pk-pk 
TP4 Base Signal Q-1 (O'scope)	.7 V pk-pk 
TP5 Base Signal Q-2 (O'scope)	.7 V pk-pk 
TP6 Emitter Signal Q-1 (O'scope)	.14 V pk-pk 
TP7 Emitter Signal Q-2 (O'scope)	.14 V pk-pk 
TP8 Collector Signal Q-1 (O'scope)	9.2 V pk-pk 
TP9 Collector Signal Q-2 (O'scope)	9.2 V pk-pk 
TP11 Output Signal (O'scope)	1.5 V pk-pk 
TP-4 to TP-6 V_{EB} Q-1 (PSM-6)	.08 V
TP-5 to TP-7 V_{EB} Q-2 (PSM-6)	.08 V

Figure 37-2. Normal Signals

d. With the scope check TP6, measure and record your findings in the appropriate block on figure 37-3.

e. What effect did opening R-3 have on the emitter signal of Q1?

f. What effect did opening R-3 have on the output signal?

7. Look at the rear panel and place S-3 in the up position and S-2 in the down position.

a. Measure the signal at TP11 and record in appropriate block on figure 37-3.

b. Changing S-3 to the up position has what effect on the output signal?

c. What effect did changing S-3 have on Q2?

d. What effect did changing S-3 have on Q1? 232

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8. Look at the rear panel and place S-3 in the down position and S-4 in the up position.

   a. Measure the output signal at TP11 and record on figure 37-3.

   b. How was the output signal affected?

   c. How was the bias on Q1 affected?

9. Place S-4 in the down position and S-5 in the up position.

   a. What is the purpose of R-4?

   b. What effect would opening R-4 have on the output signal?

   c. With the scope measure and record the Pk-Pk. Amplitude and signal at TP11 in the appropriate block on figure 37-3.

   d. Measure TP7 and record your findings in the appropriate block on figure 37-3.

   e. What effect did opening R-4 have on the signal at TP11?

   f. What effect did opening R-4 have on the bias of Q2?

10. Place S-5 in the down position and S-6 in the up position.

   a. With S-6 in the up position what effect should this have on the output signal?

   b. Measure and record the Pk-Pk. Amplitude and signal in the appropriate block on figure 37-3.

   c. What effect did changing S-6 have on the signal at TP11?

   d. What effect did changing S-6 have on the bias of Q2?

11. After completion of the practical notify your instructor that you are ready for the Criterion Progress Check.

MODULE SELF-CHECK

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

QUESTIONS:

1. Changing the forward bias on a push-pull power amplifier affects
   a. class of operation
   b. crossover distortion
   c. efficiency
   d. all of the above

2. With normal forward bias applied to the transistors within their specification for a push-pull amplifier, what class of operation will the amplifier operate?
   a. class A
   b. class AB
   c. class B
   d. class C

3. With only a slight amount of forward bias applied to the transistors in a push-pull amplifier, what class of operation will it operate?
   a. class A
   b. class AB
   c. class B
   d. class C

4. A push-pull amplifier operating at class B would have
   a. full forward bias
   b. slightly forward bias
   c. reverse bias
   d. zero bias

5. In the paraphase amplifier circuit in figure 1, select the correct DC current path.
   a. from ground through R2, Q1, R3 to $-V_{CC}$
   b. from $-V_{CC}$ through R1, Q1, R2 to ground
   c. from $-V_{CC}$ through R3, R1, Q1, R2 to ground

6. The output signal of figure 1 is taken from
   a. point A
   b. point B
   c. points A and B

7. The relation of the output signals at point A to point B is ______________.

MODULE SELF-CHECK

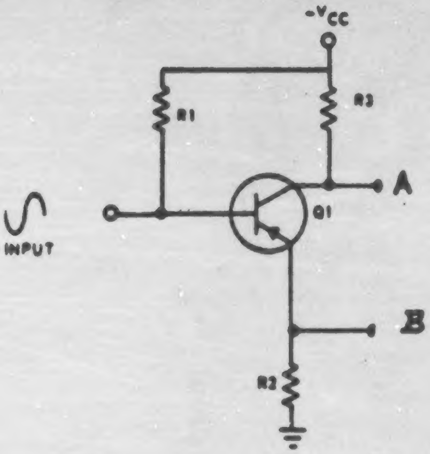
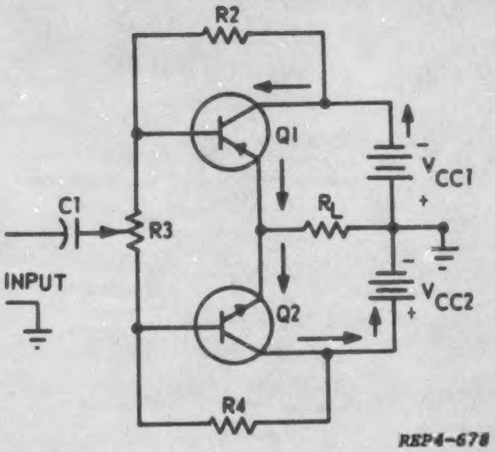


Figure 1



REP4-678

Figure 2. Complementary-Symmetry Circuit

8. If resistors R2 and R3 equal each other in figure 1, the amplitude of the output signals at point A and point B will be ________________ .

9. Select the correct statement that describes the input signal requirements for a complementary symmetry circuit.

   a. two inputs with 180 degree phase difference.

   b. two inputs in phase

   c. one signal input

10. The voltage gain in a complementary symmetry circuit is accomplished by the push-pull action of the transistor. (TRUE) (FALSE)

11. Referring to figure 2, a negative going input signal will cause transistor Q1 to __________ .

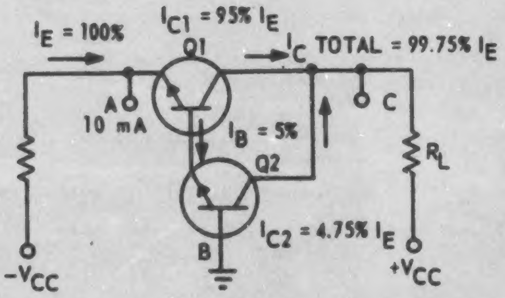
12. Referring to figure 2, a negative going input signal will cause transistor Q2 to __________ .

13. When Q1 in figure 2 is conducting, the correct current path for Q1 is from the negative side of V_{CC1}, through Q1, RL to the positive side of V_{CC1}. (TRUE) (FALSE)

14. A compounded-connected amplifier is a circuit designed to increase ____________ .

15. The total current of the circuit in figure 3 will pass through R_L. (TRUE) (FALSE)

16. Given the alpha of each transistor in figure 3 equal to .95, compute the total current flow I_C at point C.



REP4-681

Figure 3. Compound-Connected Common Base

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK

1. d
2. a
3. b
4. d

5. c
6. c
7. 180 degrees out of phase
8. equal
9. c
10. True
11. conduct (harder)
12. conduct less
13. True
14. alpha (gain)
15. False
16. 99.75

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.

	Normal	Trouble #1	Trouble #2	Trouble #3	Trouble #4	Trouble #5	Trouble #6
TP-1 Input Signal (O'scope)							
TP-4 Base Q1 (O'scope)							
TP-5 Base Q2 (O'scope)							
TP-6 Emitter Q2 (O'scope)							
TP-7 Emitter Q2 (O'scope)							
TP-8 Collector Q1 (O'scope)							
TP-9 Collector Q2 (O'scope)							
TP-11 Output Signal (O'scope)							
TP-4 to TP-6 VEB Q1 (PSM-6)							
TP-5 to TP-7 VEB Q2 (PSM-6)							

Figure 37-3 Troubleshooting Summary Chart

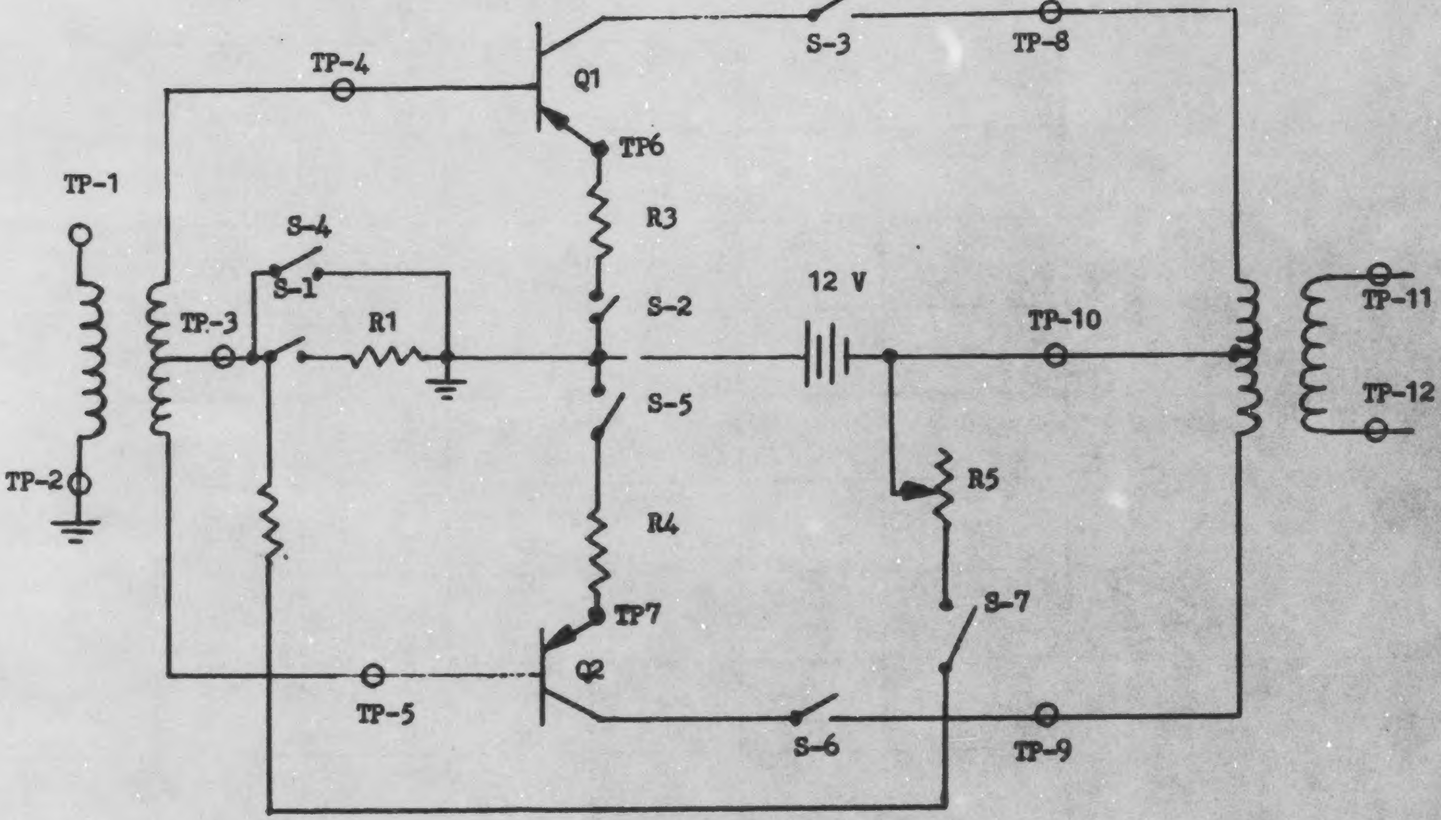

TP-4
Q1
S-3
TP-8
TP6
R3
TP-1
S-4
S-1
TP-3
R1
S-2
12 V
TP-10
TP-11
TP-12
TP-2
S-5
R5
R4
S-7
TP7
Q2
TP-5
S-6
TP-9

Figure 37-4. Transistor Push-pull Amplifier

ATC HO 3AQR3X020-X
Prepared by Keesler TTC
KEP-HO-37

Technical Training

Electronic Principles (Modular Self-Paced)

Module 37

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

February 1976

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

ATC Keesler 6-3740

DO NOT USE ON THE JOB

CHANGE 1
KEP-GP-37
1 August 1974
Effective 1 February 1976

Page 1 - OBJECTIVE: e. Given a trainer having an inoperative transistor push-pull power amplifier, schematic diagram, multimeter, and oscilloscope, determine the faulty component two out of three times.

Page 2 - AUDIOVISUALS: Television Lesson 30-359, Transistorized Push-Pull Amplifier and Television Lesson 30-436, Complementary Symmetry

Page 13 through 21: Use Laboratory Exercise 37-1 contained in this Change.

Page 25 and 26: Delete

LABORATORY EXERCISE

37-1

TROUBLESHOOTING SOLID STATE POWER AMPLIFIERS

OBJECTIVE : Given a trainer having an inoperative transistor push-pull power amplifier, schematic diagram, multimeter and oscilloscope, determine the faulty component two out of three times.

EQUIPMENT:

- Transistor Push-Pull Amplifier
- Transistor Power Supply
- Oscilloscope
- Multimeter
- Signal Generator

REFERENCES: Student Text, Volume V, Chapter 5.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES, REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Trainer Analysis: Refer to figure 1 in Handout 37 to locate the components as each of the following trainer functions are identified:

a. T1 couples an input signal to the bases of amplifiers Q1 and Q2. The base signals are equal in amplitude and 180 degrees out of phase.

b. R1, R2 and R5 form a variable voltage divider to develop forward bias, when S7 is closed (left position).

c. R3 and R4 are emitter swamping resistors.

d. T2 couples the collector signals to load resistor R6.

e. The battery symbol represents an external power supply.

f. The following troubles can be inserted by switches located in a panel on the front of the trainer:

(1) Open R2 (Removes forward bias).

(2) Open R3 (Opens emitter circuit of Q1).

(3) Open Collector Q1 (Disables Q1).

(4) Shorted R1 (Makes forward bias zero).

(5) Open R4 (Opens emitter circuit of Q2)

(6) Open Collector Q2 (Disables Q2)

NOTE: Trouble switches are not shown in figure 1 in Student Handout 37.

2. Equipment Preparation:

a.	Oscilloscope Controls	Position
(1)	POWER	ON
(2)	VOLTS/CM (CH1)	.5 V CAL
(3)	VOLTS/CM (CH2)	.5 V CAL
(4)	CHOP-ALT	ALT
(5)	SEPARATE-CH1&CH2	SEPARATE
(6)	INVERT CH2	Pushed in
(7)	TRIG SELECT LEVEL	EXT + AUTO
(8)	AC-ACF-DC	AC
(9)	Vertical Position (CH1)	1 cm above center
(10)	Vertical Position (CH2)	1 cm below center
(11)	TIME/CM	.5 mS CAL
(12)	AC-GND-DC (CH1 and CH2)	AC

b. Signal Generator Controls	Position
(1) POWER	ON
(2) SINE WAVE AMPLITUDE	Minimum
(3) SINE WAVE RANGE	1 Volt
(4) FREQUENCY MULTIPLIER	10
(5) FREQUENCY	100

c. Trainer	Position
(1) R5	Fully Counterclockwise
(2) S7	Left (Closed)
(3) S1 through S6 (trouble switches)	down

d. Interconnections:

(1) Signal generator ground to trainer TP2

(2) Sine wave output of signal generator to trainer TP1

(3) Oscilloscope ground to trainer TP12

(4) Oscilloscope EXT TRIG input to signal generator sine wave output

(5) Connect power supply to the trainer and set the output voltage adjustment fully counterclockwise.

(6) Plug power supply into T-bench power source.

3. Activity - Trainer Familiarization

a. Set the multimeter FUNCTION to DCV 20kΩ/V and RANGE to 10 and connect the multimeter between TP10 (black lead) and ground (red lead).

b. Turn the power supply ON and set the output voltage to - 8 volts. Remove the multimeter leads.

NOTE: If power is lost, reset power supply by turning OFF and back ON.

c. Connect oscilloscope CH1 to TP1 and adjust the sine wave amplitude control of the signal generator to obtain a 2 volt Pk-Pk input signal.

d. Compare amplitude and phase relationship of the input signals.

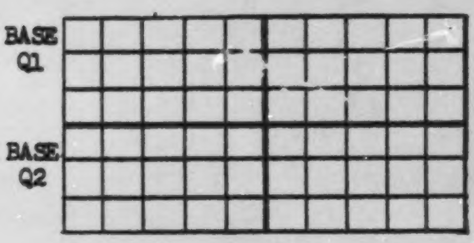
(1) Move CH1 to TP4 and measure the signal amplitude on the base of Q1.

_______________Volts Pk-Pk.

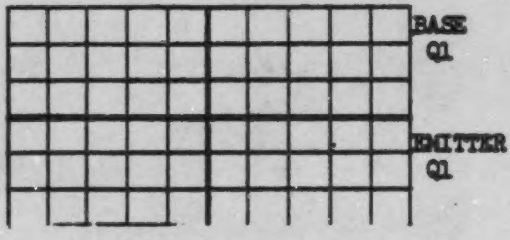
(2) Connect oscilloscope CH2 to TP5 and measure the signal amplitude on the base of Q2

_______________Volts Pk-Pk.

(3) Draw the two signal waveshapes on graph A. Indicate signal amplitude and phase relationship



Graph A



Graph B

e. Compare the base and emitter waveshapes of Q1.

(1) Use CH1 display of TP4 and draw the base waveshape of Q1 on graph B.

(2) Move CH2 from TP5 to TP6 to observe the emitter waveshape of Q1.

(3) Draw the emitter waveshape of Q1 on graph B.

(4) Compare the two signals and answer the following:

(a) The negative alternation of the base signal causes Q1 to _______________.

(b) The flat portion of the emitter signal indicates___________ _______________.

NOTE: Since the transistors share a common biasing circuit, operating characteristics of both transistors can be determined by measurements taken on one transistor.

f. Transistor cutoff and conduction times and the relationship to crossover distortion.

(1) Observe the emitter waveshape of Q-1(CH2,TP6) and measure the cutoff and conduction times.

(a) Cutoff Time________________Milliseconds

(b) Conduction Time____________Milliseconds

(c) The transistors are (conducting)(cutoff) longer than they are (conducting)(cutoff).

(d) The transistors are operating class__________.

(2) Observe amplifier output.

(a) Move CH1 of the oscilloscope to TP11 to observe amplifier output and slowly turn R5 clockwise.

(b) As R5 is turned clockwise, crossover distortion (increases) (decreases).

(3) With R5 fully clockwise, observe the emitter waveshape of Q-1 (CH2,TP6) and measure cutoff and conduction times.

(a) Cutoff time______________milliseconds.

(b) Conduction time__________milliseconds.

(c) The transistors are operating class_______.

g. Determine the effect of bias on crossover distortion.

(1) Set the multimeter FUNCTION to 20kΩ/V and RANGE to .5.

(2) Measure the bias voltage between TP5 (NEG) and TP7 (POS) while slowly turning R5 counterclockwise.

(3) Using the information obtained in steps f and g, answer the following:

(a) As (forward)(reverse) bias is (increased)(decreased), crossover distortion increases.

(b) Crossover distortion is less when the transistors are operated class________.

(4) Set R5 to a position where the least distortion is displayed at the output (TP11).

h. Determine the effect of input signal on bias.

(1) Use multimeter to measure and record bias on Q2 from TP5 (NEG) to TP7(POS). Forward bias_______volts.

(2) Remove signal generator input at TP1. Measure and record bias of Q2. Forward bias________volts.

(3) The input signal causes the forward bias to (increase)(decrease).

(4) Reconnect signal generator to TP1

CONFIRM YOUR ANSWERS

4. Activity - Troubleshooting

a. Set the trainer for normal operation

(1) Use CH1 of oscilloscope and adjust the input signal at TP1 for 1 volt Pk-Pk.

(2) Use CH1 of the oscilloscope and the multimeter to adjust R5 for equal conduction and cutoff time of transistor Q1.

b. Record the NORMAL MEASURED VALUES on the Troubleshooting Summary Chart in Student Handout HO-37. Compare the measured values with those listed in the NOMINAL VALUES column of the Summary Chart.

c. Insert the following troubles and record the circuit measurements in the trouble column of chart 1, HO-37.

(1) Trouble #1 - OPEN R3. Move S2 UP.

(a) Which measured values changed with this trouble?

____

____

(b) The trouble affects the circuitry associated with (Q1)(Q2).

(c) Was there a signal at the emitter and collector of Q1? Why?

____

____

____

(d) Was the output (TP11) distorted? If so, how was it distorted?

CONFIRM YOUR ANSWERS AND REMOVE TROUBLE (S2 DOWN)

(2) Trouble #2 - Q1 OPEN Move S3 UP.

(a) Which measured values changed with this trouble?

(b) The trouble affects the circuitry associated with (Q1)(Q2).

(c) Was there a signal at the emitter of Q1? If so, why?

(d) Was there a signal at the collector of Q1?

(e) Was the output (TP11) distorted? If so, how was it distorted?

CONFIRM YOUR ANSWERS AND REMOVE TROUBLE (S3 DOWN)

(3) Trouble #3 - R1 SHORTED Move S4 UP.

(a) Which measured values changed with this trouble?

____

____

(b) The trouble affects the circuitry associated with (Q1)(Q2)(Both).

(c) How did this trouble affect the waveshapes observed at the transistor collectors.

____

____

____

(d) Could the faulty component be located with an Ohmmeter? How?

____

____

____

CONFIRM YOUR ANSWERS AND REMOVE TROUBLE (S4 DOWN)

(4) Trouble #4 - R4 OPEN Move S5 UP.

(a) Which measured values changed with this trouble?

____

____

(b) The trouble affects the circuitry associated with (Q1)(Q2).

(c) Was there a signal at the emitter and collector of Q2? Why?

____

____

____

(d) Was the output(TP11) distorted? If so, how was it distorted?

CONFIRM YOUR ANSWERS AND REMOVE TROUBLE(S4 DOWN)

(5) Trouble #5 - Q2 OPEN Move S6 UP.

(a) Which measured values changed with this trouble?

(b) The trouble affects the circuitry associated with (Q1)(Q2).

(c) Was there a signal at the emitter of Q2? If so, why?

(d) Was there a signal at the collector of Q2?

(e) Was the output (TP11) distorted? If so, how was it distorted?

CONFIRM YOUR ANSWERS AND REMOVE TROUBLE (S6 DOWN)

5. Summary

a. The input signals to the bases of Q1 and Q2 are equal in amplitude and (in)(180° out of) phase.

b. Class AB operation of the transistors requires (more)(less) forward bias than Class C and produces (minimum)(maximum) crossover distortion in the output.

c. Decreasing forward bias will(increase)(decrease) crossover distortion.

d. Match the following trouble symptoms with the malfunctioning circuit:

Symptom	Malfunction
(1) Negative portion of the output at TP11 is missing.__________	(a) Q1 Circuitry
(2) Change in class of operation from B to C. ________	(b) Q2 Circuitry
(3) Positive portion of the output at TP11 is missing.______	(c) Bias Network

CONFIRM YOUR ANSWERS

CONSULT YOUR INSTRUCTOR FOR PROGRESS CHECK.

ANSWERS TO LABORATORY EXERCISE 37-1

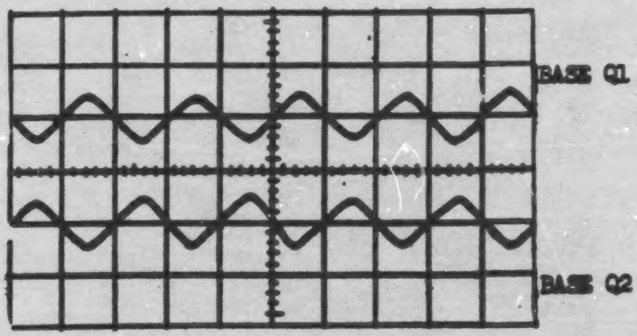
NOTE: Measurements will vary with each trainer.

3. Activity - Trainer Familiarization

d(1) .75

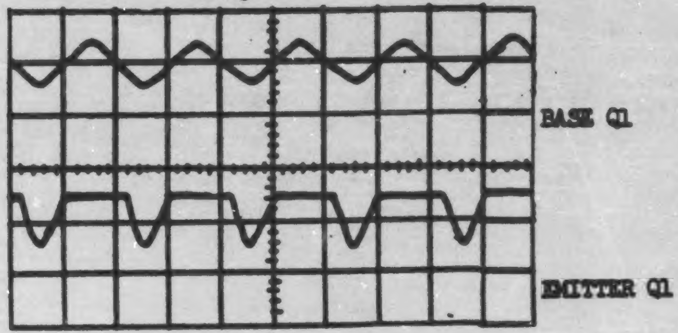
d(2) .75

d(3)



Graph A

e(1) & (3)



Graph B

e(4)(a) conduct

e(4)(b) cut off

f(1)(a) .6

f(1)(b) .4

f(1)(c) cutoff, conducting

f(1)(d) C

f(2)(b) decreases

f(3)(a) .35

f(3)(b) .65

f(3)(c) AB

g(3)(a) forward, decrease

g(3)(b) AB

h(1) .03

h(2) .14

h(3) increase

4. Activity - Troubleshooting

Step c

(1)(a) TP6, TP8, TP9, TP11 and TP4 to TP6.

(1)(b) Q1

(1)(c) Yes. The signal coupled from base to emitter. Autotransformer coupled by the primary of T2 from collector of Q2 to collector of Q1.

(1)(d) Yes. Negative alternation clipped.

(2)(a) TP4, TP6, TP8, TP9 and TP11.

(2)(b) Q1

(2)(c) Very small. Q1 does not conduct emitter to collector.

(2)(d) Yes. Autotransformer coupled by primary of T2 from collector of Q2.

(2)(e) Yes. Negative alternation clipped.

(3)(a) TP6, TP7, TP8, TP9, TP11, TP4 to TP6 and TP5 to TP7.

(3)(b) both Q1 and Q2
(3)(c) Smaller than normal. Severe crossover distortion.
(3)(d) Yes. Measure resistance from T1 center tap to ground with power off.

(4)(a) TP7, TP8, TP9, TP11 and TP5 to TP7.

(4)(b) Q2

(4)(c) Yes. Signal is still coupled from base to emitter. Autotransformer coupled by primary of T2 to collector of Q2.

(4)(d) Yes. Positive alternation clipped.

(5)(a) TP5, TP7, TP8, TP9 and TP11.

(5)(b) Q2

(5)(c) Very small. Q2 is not conducting from emitter to collector.

(5)(d) Yes. Signal is autotransformer coupled from collector of Q1 to collector of Q2.

(5)(e) Yes. Positive alternation clipped.

5. Summary

   a. 180° out of

   b. more, minimum

   c. increase

   d. (1)-a, (2)-c, (3)-b

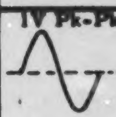
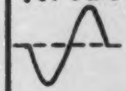
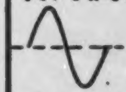
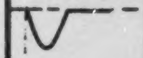
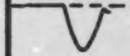
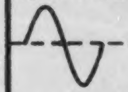
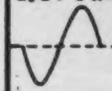
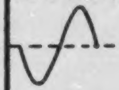
TEST POINTS	NOMINAL VALUES	NORMAL MEASURED	TROUBLE R-3 OPEN	TROUBLE Q-1 OPEN	TROUBLE R-1 SHORT	TROUBLE R-4 OPEN	TROUBLE Q-2 OPEN
TP1 - TP2 INPUT SIGNAL (Oscilloscope)	1V Pk-Pk 						
TP4 - GND BASE Q1 (Oscilloscope)	.4V Pk-Pk 						
TP5 - GND BASE Q2 (Oscilloscope)	.4V Pk-Pk 						
TP6 - GND EMITTER Q1 (Oscilloscope)	.2V Pk-Pk 						
TP7 - GND EMITTER Q2 (Oscilloscope	.2V Pk-Pk 						
TP8 - GND COLLECTOR Q1 (Oscilloscope)	2.2V Pk-Pk 						
TP9 - GND COLLECTOR Q2 (Oscilloscope)	2.2V Pk-Pk 						
TP11 - TP12 OUTPUT SIGNAL (Oscilloscope)	.5 V Pk-Pk 						
TP4 - TP6 V_{EB} Q1 (Multimeter)	-.1VDC						
TP5 -TP7 V_{EB} Q2 (Multimeter)	-.1VDC						

Chart 1. Troubleshooting Summary Chart.

THIS HANDOUT WILL BE USED WITH KEP-GP-37

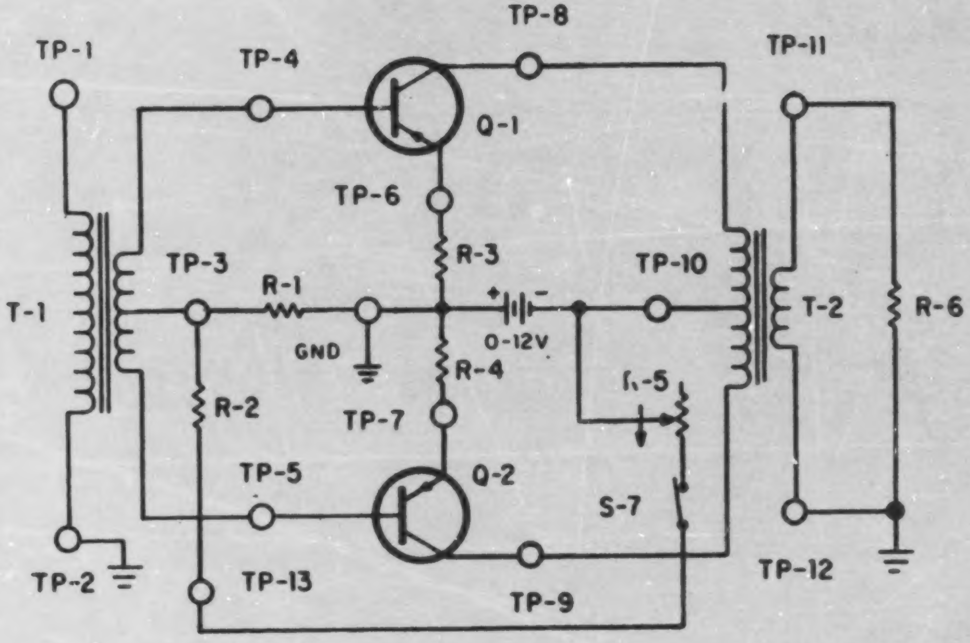

TP-1
TP-4
TP-8
TP-11
Q-1
TP-6
R-3
TP-3
R-1
TP-10
T-1
T-2
R-6
GND
0-12V
R-4
R-5
R-2
TP-7
TP-5
Q-2
S-7
TP-2
TP-13
TP-9
TP-12

Figure 1. Transistor Push-Pull Amplifier

ATC GP 3AQR3X020-X

Prepared by Keesler TTC
KEP-GP-38

Technical Training

Electronic Principles (Modular Self-Paced)

Module 38

TROUBLESHOOTING SOLID STATE NARROW BAND AMPLIFIERS

December 1975

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

ATC Keesler 6-2580

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-38
December 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 38

TROUBLESHOOTING SOLID STATE NARROW BAND AMPLIFIERS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, which will enable you to satisfy the learning objectives.

CONTENTS

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List of Resources	1
Adjunct Guide	1
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Answers	12

OVERVIEW

1. SCOPE: Devices which amplify signals in the RF spectrum are sometimes called NARROW BAND AMPLIFIERS. When a radio, television, or radar signal is picked up by an antenna it is usually very weak and in the order of millivolts or even microvolts in amplitude. Narrow band amplifiers are used to amplify these weak signals enough that they can be used, eventually, to drive some load. Because of the frequency range of these amplifiers, interelement and stray capacitance and inductance, feedback, and interstage coupling become critical. This chapter discusses the neutralization and unilateralization of narrow band amplifiers, effects of load changes on Q and bandwidth, feedback, interstage coupling, and troubleshooting.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives.

a. Given a list of statements, select the one which describes the effects of load changes on Q and bandwidth of a narrow band amplifier.

b. Given a list of statements, select the one which describes the effects of regenerative feedback on narrow band amplifier stability; distortion; gain.

c. Given frequency response curves for transformer coupling, select the ones which identify undercoupling; overcoupling; critical coupling.

d. Given schematic diagrams of narrow band amplifiers, identify the neutralization or unilateralization components.

e. Given a transistor radio frequency amplifier trainer, multimeter, and oscilloscope, plot the frequency response curve and determine the bandpass and bandwidth at the half power points within ±10 percent accuracy.

Supersedes KEP-GP-38, dated 1 June 1975.

f. Given a trainer having an inoperative transistor narrow band amplifier, schematic diagram, multimeter, and oscilloscope, determine the faulty component two out of three times.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text V

LABORATORY EXERCISE:

38-1, Troubleshooting Solid State Narrow Band Amplifiers

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

In this module you will study circuits that operate in the radio frequency spectrum. These radio frequency (RF) circuits are generally classified as narrow band amplifiers. Most of your previous study has been associated with current operated devices in the low frequency audio range which differs considerably in characteristics from RF amplifiers. This chapter investigates the terms and operational characteristics of RF amplifiers, methods of coupling, cascaded RF amplifiers, and trouble analysis. Study the material carefully as you will encounter RF amplifiers wherever radio frequency signals are used.

A. Turn to Student Text, Volume V, and read paragraphs 6-1 through 6-13. Return to this page and answer the following questions.

1. By comparison to a single stage RF amplifier, the resultant bandwidth of two or more RF stages connected in cascade is ______________________.

2. What is the effect on selectivity of a receiver where additional stages of tuned circuits are added? ______________________

____

3. Referring to figure 38-1, the selection of the signal(s) to be amplified by Q1 is accomplished by what components? ______________

____

4. Where is the input signal voltage for Q1 developed in figure 38-1? ______________

____

5. Why are the antenna and collector tank circuits tuned to resonate at the same frequency? ______________________

____

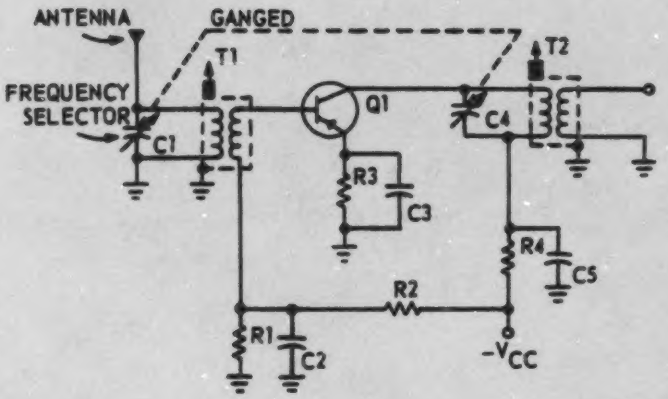


Figure 38-1. Transistor RF Amplifier

6. The response curves for each stage of a three-stage cascade tuned RF amplifier will be identical. (True) (False)

7. Noise voltages at the limits of the bandpass can be minimized by decreasing the bandwidth. (True) (False)

CONFIRM YOUR ANSWERS.

B. Turn to Student Text, Volume V, and read paragraphs 6-14 through 6-30. Return to this page and answer the following questions.

Refer to figure 38-1 for questions 1 through 4.

1. Given the following symptoms, determine the malfunction:

   a. Output signal lower than normal.

   b. Bandwidth increased.

   c. Collector voltage normal.

   d. f_r of first tank higher than normal.

2. Given the following symptoms, determine the malfunction:

   a. No output signal.

   b. Collector voltage (V_C of Q1 is zero).

   c. Bias voltage to Q1 present.

3. Given the following symptoms, determine the malfunction:

   a. No output signal at secondary of T2.

   b. DC voltage in collector circuit slightly higher than normal.

   c. Q1 checks good.

4. Given the following symptoms, determine the malfunction:

   a. No output signal.

   b. Bias voltage normal.

   c. Collector voltage normal.

5. Narrow band amplifiers use resonant circuits to establish the selectivity and sensitivity of the system. (True) (False)

CONFIRM YOUR ANSWERS.

C. Turn to Student Text, Volume V, and read paragraphs 6-31 through 6-54. Return to this page and answer the following questions.

1. The primary and/or secondary windings of RF transformers are tank circuits tuned to a specific resonant frequency. (True) (False)

2. Why is it desirable for tuned RF circuits to have a relatively high Q? ______________

____

3. One of the functions of an interstage transformer is to match the ______________ output resistance of one stage to the ______________ input resistance of the next stage.

4. In a double tuned transformer circuit, both the primary and the secondary windings contain tunable resonant circuits. (True) (False)

5. What three factors affect the bandpass characteristics of a double tuned transformer circuit? ______________

____

____

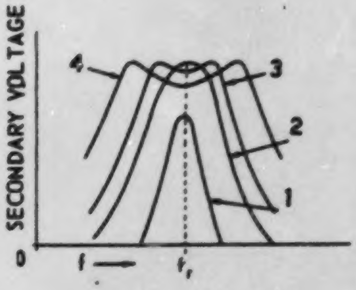


Figure 38-2. Double Tuned Transformer Response Curves

Refer to figure 38-2 for questions 6 through 10.

6. The response curve numbered #1 would depict what type of coupling? ______________

7. Optimum coupling would be represented by curve number ______________.

8. Critical coupling would be shown by curve number ______________.

9. Curve number 4 represents ______________.

10. Select the curve which would illustrate the maximum transfer of energy in a double tuned transformer circuit. ______________

11. The characteristics and physical construction of transformers used as coupling devices at high frequencies are the same as those used in audio frequencies. (True) (False)

CONFIRM YOUR ANSWERS.

D. Turn to Student Text, Volume V, and read paragraphs 6-55 through 6-67. Return to this page and answer the following questions.

1. The transferring of energy from a high level point back to a low level point in a system is known as ______________.

2. What are the two types of feedback?

____

____

3. The type of feedback that opposes the input signal is known as ______________.

4. The type of feedback which aids the input signal is known as ______________.

5. What type of feedback is used when a high gain is required from a stage?

____

6. The means by which a circuit is made to transfer energy in only one direction is called ___________________________.

7. The process of providing degenerative feedback to cancel the effects of regenerative feedback is known as _________________.

8. Neutralizing components are used to compensate for _______________________ feedback in transistors.

CONFIRM YOUR ANSWERS.

E. Turn to Laboratory Exercise 38-1 and complete all sections before returning to this page. If you have any difficulty, contact your instructor. The material in this laboratory exercise is arranged to give you experience in troubleshooting solid state narrow band amplifiers. After performing this exercise return to this page.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 38-1

OBJECTIVES:

1. Given a transistor radio frequency amplifier trainer, multimeter and oscilloscope, plot the frequency response curve and determine the bandpass and bandwidth at the half power points within ±10 percent accuracy.

2. Given a trainer having an inoperative transistor narrow band amplifier, schematic diagram, multimeter, and oscilloscope, determine the faulty component two out of three times.

Upon completion of this exercise, have your instructor initial these objectives on your progress check.

EQUIPMENT:

1. Solid State Radio Frequency Amplifier (Trainer #5971)
2. Solid State Power Supply (Trainer #4649)
3. Oscilloscope
4. Multimeter

REFERENCES:

Student Text, Chapter 6

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Analysis of the Trainer

a. The RF amplifier trainer schematic is shown in figure 38-3.

b. The trainer incorporates a variable resistor (R101) for varying forward bias on Q101 (gain control).

c. The trainer has a built-in signal generator with controls for varying the frequency and the amplitude of the input signal.

d. The trainer has a switch (S101) for inserting or removing the emitter bypass capacitor (C102).

2. Preparation of Equipment

a. Oscilloscope

Controls	Position
POWER	ON
CH1 Vert. Pos.	Midposition
CH1 VOLTS/CM	.5 CAL
CHOP/ALT	ALT
CH1 AC/GND/DC	AC
TRIG SELECT	CH1 +
LEVEL	AUTO
PULLX10MAG	Push in
SEPARATE/ CH1 & CH2	SEPARATE
AC/ACF/DC	ACF

NOTE: Connect the oscilloscope ground to the trainer ground.

b. Trainer Controls

FREQUENCY	455 kHz (approx)
AMPLITUDE	Fully Clockwise
GAIN	Fully Clockwise
S101	Right

c. Power Supply to Trainer

(1) Connect power supply to trainer with power cable.

(2) Set V_{CC} for 8 volts (use multimeter to check TP105 and ground).

3. Activity

a. INSTRUCTION: Preliminary adjustments. Observe the signal at TP106. Adjust the TIME/CM on the oscilloscope for several cycles of display.

b. Adjust the AMPLITUDE CONTROL on the trainer for a signal display on the oscilloscope.

c. Adjust the FREQUENCY CONTROL on the trainer for maximum signal amplitude on the oscilloscope.

d. Adjust the GAIN CONTROL on the trainer for maximum signal amplitude on the oscilloscope.

e. Alternately adjust the FREQUENCY CONTROL for maximum signal amplitude and the AMPLITUDE CONTROL for 1 volt peak to peak signal. (Use the 0.2 VOLT/CM setting.)

IF YOU ARE UNABLE TO OBTAIN 1 VOLT PEAK TO PEAK, CALL THE INSTRUCTOR.

NOTE: DO NOT CHANGE THE SETTING OF THE AMPLITUDE OR GAIN CONTROL FOR THE REMAINDER OF THIS PRACTICAL EXERCISE.

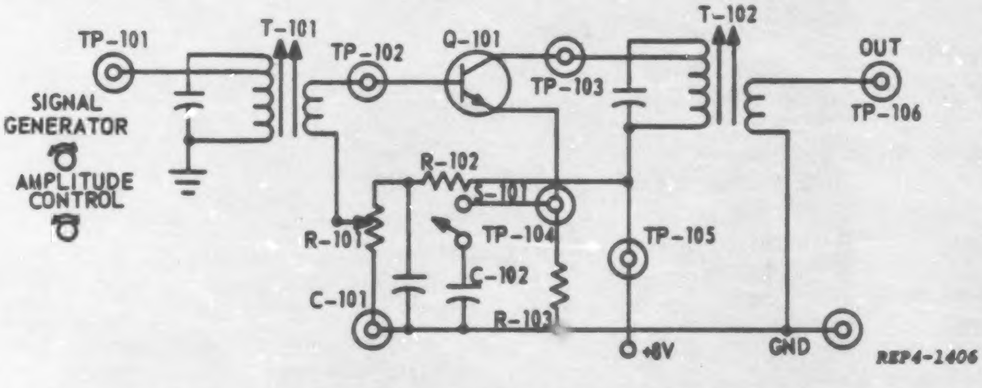

TP-101
T-101
TP-102
Q-101
T-102
OUT
TP-103
TP-106
SIGNAL GENERATOR
AMPLITUDE CONTROL
R-102
S-101
TP-104
R-101
TP-105
C-102
C-101
R-103
+8V
GND
REP4-1406

Figure 38-3. Transistor Radio Frequency Amplifier

	FREQUENCY	AMPLITUDE
-50 kHz		
-40 kHz		
-30 kHz		
-20 kHz		
-10 kHz		
f_r kHz		
+10 kHz		
+20 kHz		
+30 kHz		
+40 kHz		
+50 kHz		

REP4-1404

Figure 38-4. Record of Frequency/Amplitude

f. Record the resonant frequency from the trainer FREQUENCY CONTROL (f_r to the nearest 10 kHz), and the amplitude from the oscilloscope in the appropriate place in figure 38-4.

(1) Using the frequency control adjustment, decrease the frequency by 10 kHz. Record the frequency and amplitude on the line labeled -10 kHz in figure 38-4.

(2) Continue to decrease the frequency in 10 kHz steps and record the frequency and amplitude in the appropriate areas of figure 38-4.

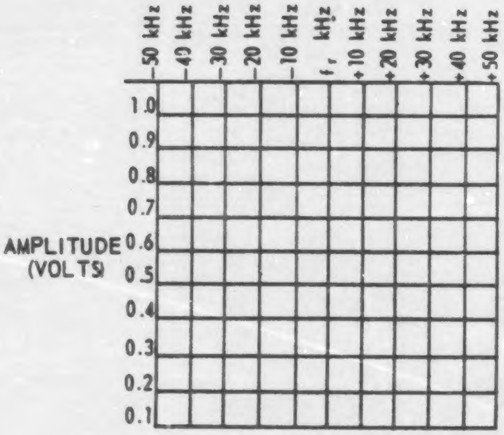
(3) Return the frequency control to the resonant frequency.

(4) Using the frequency control adjustment, increase the frequency by 10 kHz. Record the frequency and amplitude on the line labeled +10 kHz in figure 38-4.

(5) Continue to increase the frequency in 10 kHz steps and record the frequency and amplitude in the appropriate areas of figure 38-4.

g. Analysis of frequency response curve:

(1) Plot the frequencies and amplitudes recorded in figure 38-4 on figure 38-5 by placing a dot at the intersection of the frequency and voltage levels.



REP4-1405

Figure 38-5. Frequency Response Curve

(2) Draw a connecting line between each amplitude/frequency value in figure 38-5.

(3) Mark the half power points on the frequency response curve (half power points = .707 x E_{pk}).

(4) The frequency at the lower half power point = ____________ kHz.

(5) The frequency at the upper power point = ________________ kHz.

(6) The bandpass is from _________ kHz to _________ kHz.

(7) The bandwidth is ___________ kHz.

CONFIRM ANSWERS WITH INSTRUCTOR.

h. Return the frequency control to the resonant frequency.

4. Activity

The remainder of this practical exercise is devoted to troubleshooting analysis of the problems inserted within the trainer which will make it inoperative or function abnormally. This laboratory exercise will provide practice in associating symptoms of a malfunction to a specific trouble and will be conducted in the following sequence.

MEASUREMENT POINTS	NORMAL	1. OPEN T-1 PRI.	2. OPEN T-1 SEC.	3. OPEN Q-1 EMITTER	4. OPEN Q-1 COLL.	5. OPEN T-2 PRI.
a. Primary Signal Voltage (Pk-Pk) TP101 to Gnd						
b. Base Signal Voltage (Pk-Pk) TP102 to Gnd						
c. Collector Signal Voltage (Pk-Pk) TP103 to Gnd						
d. Output Signal Voltage (Pk-Pk) TP-106 to Gnd						
e. Q101 Base Voltage (V_B) TP102 to Gnd						
f. Q101 Emitter Voltage (V_E) TP104 to Gnd						
g. Q101 Collector Voltage (V_C) TP103 to Gnd						
h. Applied Voltage (V_{CC}) TP105 to Gnd						

Figure 38-6. Troubleshooting Summary Chart (Narrow Band Amplifier)

a. The normal voltage and waveshape measurements will be taken and recorded on the troubleshooting summary chart (figure 38-6).

b. A known trouble will then be placed in the trainer, and voltage and waveshape measurements will be taken and recorded in the appropriate blocks on figure 38-6.

c. Next you will be questioned to assure association of the abnormal readings to the inserted trouble.

d. This procedure will be repeated for all five troubles.

e. Call your instructor and he will insert an unknown trouble in your trainer. You will then take the same voltage and waveshape measurements. From their values you should be able to identify the trouble.

NOTE: Figure 38-7 illustrates the locations of the switches that simulate the five troubles that can be inserted in the trainer.

PROCEDURES FOR MEASURING VOLTAGE AND WAVESHAPES:

1. Follow procedures used in setting up the trainer and test equipment that you used in the first section of this laboratory exercise (pages 4 and 5). BE SURE TO ADJUST THE V_{CC} TO 8V AND THE INPUT WAVEFORM TO 1V PK-PK. It is necessary

to check this adjustment before each set of measurements. The first step in this part of the exercise will be to establish what the NORMAL voltages and waveforms are for the narrow band amplifier. Follow the procedure below to measure and record the values for the circuit. Record the values in the NORMAL column, figure 38-6, Troubleshooting Summary Chart, on page 7.

a. PRIMARY SIGNAL VOLTAGE (TP101 to GND). Measure and record the pk/pk amplitude of the sine wave signal observed at TP101.

b. BASE SIGNAL VOLTAGE (TP102 to GND). Measure and record the pk/pk amplitude of the sine wave signal observed at TP102.

c. COLLECTOR SIGNAL VOLTAGE (TP103 to GND). Measure and record the pk/pk amplitude of the sine wave signal observed at TP103.

d. OUTPUT SIGNAL VOLTAGE (TP106 to GND). Measure and record the pk/pk amplitude of the sine wave at TP106. This was set at 1V in preparing for the exercise. If it is no longer 1V, it should be readjusted to 1V and the preceding measurements repeated.

e. BASE VOLTAGE (V_B) on Q101 (TP102 to GND). Place the meter function switch on the 20 k/volt position and the range switch to 2.5. Measure and record the voltage between TP102 and ground.

f. Emitter voltage on Q101 (TP104 to GND). Place the meter range switch on 2.5. Record the voltage between TP104 and GND.

g. Collector voltage on Q101 (TP103 to GND). Place the meter range switch on 10. Record the voltage between TP103 and ground.

h. Applied voltage (V_{CC}). Place the range switch of the meter on 10. Measure and record the voltage between TP105 and ground.

The trainer has the capability of simulating five different troubles as indicated at the top of figure 38-6. These troubles can be simulated by selecting the proper switch located in the compartment on the trainer.

The first step will be to insert the trouble and then measure and record the voltages and waveforms in the same sequence as was followed when the measurements were made for normal circuit operation. The second step will be to compare these readings with the normal readings in an effort to establish an insight to circuit malfunctions.

EXERCISE 1 - OPEN TRANSFORMER T101 PRIMARY

Insert the trouble "Open Pri. T1" by raising the switch in the compartment. Before taking your measurements, adjust the power supply for 8V. Refer to figure 38-7 for the electrical location of the switch that simulates the trouble "Open Pri. T1." Note that the switches are labeled "T1, Q1, and T2" while on the top panel the same components are labeled "T101, Q101, and T102." If you have any questions, consult your instructor.

Follow the procedures for taking voltage and waveforms used for obtaining the NORMAL measurements. Record your measurements under "OPEN T1 PRI" on the Troubleshooting Summary Chart.

1. What measurement was significantly different from the normal? ________________

2. Why were no other measurements greatly affected? ________________________

EXERCISE 2 - OPEN TRANSFORMER T101 SECONDARY

Insert the trouble "Open Sec. T1." Follow the procedures used for Exercise 1, and answer the following questions.

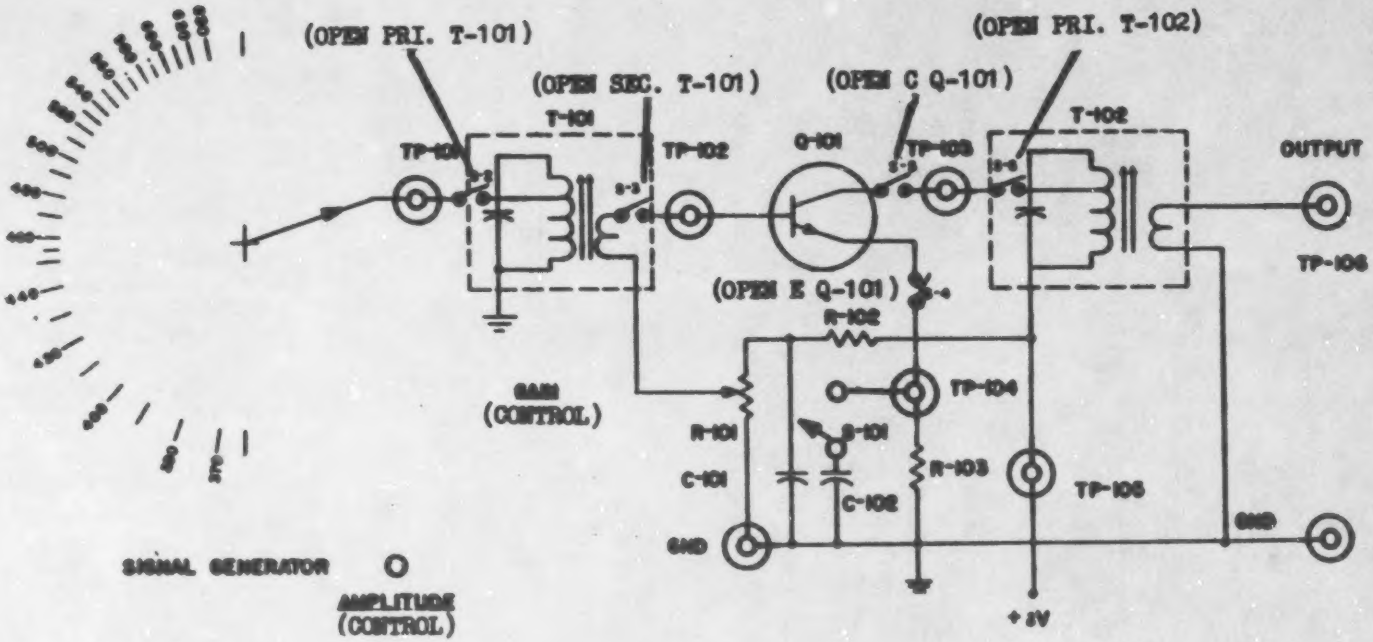

(OPEN PRI. T-101)
(OPEN SEC. T-101)
(OPEN C Q-101)
(OPEN PRI. T-102)
T-101
T-102
TP-101
TP-102
Q-101
TP-103
OUTPUT
TP-106
S-2
S-3
S-5
S-6
(OPEN E Q-101)
S-4
R-102
GAIN
(CONTROL)
TP-104
R-101
S-101
C-101
R-103
TP-105
C-102
GND
GND
+ 3V
SIGNAL GENERATOR
AMPLITUDE
(CONTROL)

Figure 38-7. Narrow Band Amplifier Troubleshooting Trainer

1. Did the voltage at TP102 change significantly? ________________

Why? ________________

____

2. Why did the voltage at TP104 reduce to almost zero? ________________

EXERCISE 3 - OPEN TRANSISTOR EMITTER Q1

Insert the trouble "Open E Q1." Follow the procedures used for exercise 1 and answer the following questions.

1. What two measurements are changed significantly when the emitter is open?

____

Why? ________________

____

EXERCISE 4 - OPEN TRANSISTOR COLLECTOR Q1

Insert the trouble "Open C Q1." Follow the procedures used for Exercise 1 and answer the following questions.

1. What is the collector voltage measured at TP103? ________________

2. Why is the collector voltage not zero?

____

3. What measurements changed greatly from NORMAL? ________________

Why? ________________

____

EXERCISE 5 - OPEN TRANSFORMER PRIMARY T2

Insert the trouble "Open Pri. T2." Follow the procedures used for Exercise 1 and answer the following questions.

1. What measurements were appreciably different from NORMAL measurements?

____

2. Which of these measurements identifies the trouble as an open in T2? ________________

Why? ________________

____

CONFIRM YOUR ANSWERS.

____

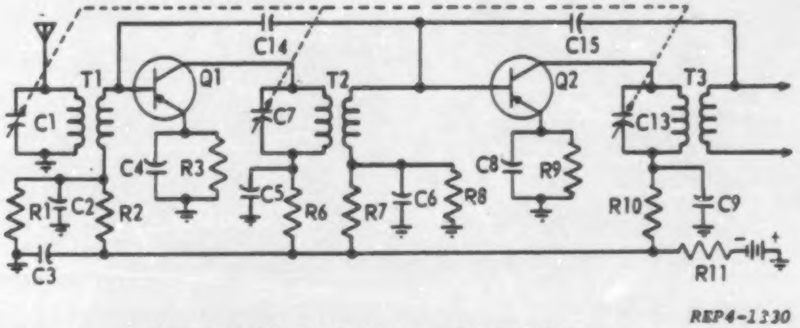
MODULE SELF-CHECK

1. Identify the two neutralizing components in the two stage RF amplifier shown in figure 38-8. ________________

____

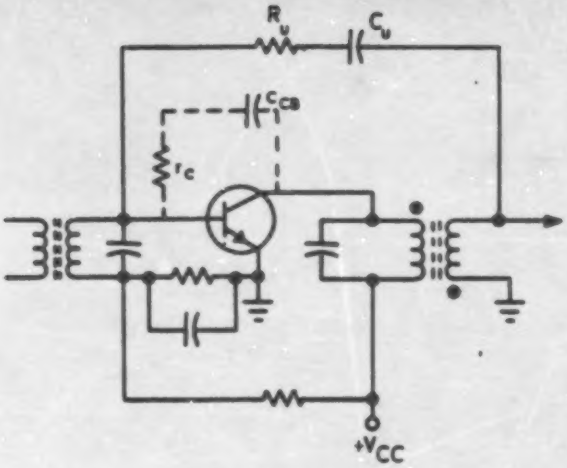
2. Neutralizing components are used to cancel what type of feedback in transistors?

____



REP4-1330

Figure 38-8. Two-Stage RF Amplifier



REP4-1329

Figure 38-9. Unilateralized Tuned Amplifier

3. Neutralizing components provide degenerative feedback to compensate for the regenerative effect of reactive feedback in transistors. (True) (False)

4. Identify the two unilateralization components in the circuit shown in figure 38-9.

____

5. Unilateralization components are used to cancel what type of feedback in an RF transistor amplifier? ________________

6. Increasing the load on a narrow band amplifier results in an:

___ a. Increased Q and bandwidth.

___ b. Increased Q and decreased bandwidth.

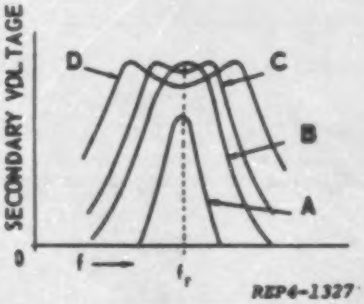
___ c. Decreased Q and increased bandwidth.

___ d. Decreased Q and decreased bandwidth.

7. When regenerative feedback is used in a narrow band amplifier the stability decreases. (True) (False)

8. When regenerative feedback is used in a narrow band amplifier, distortion ________________________________.

9. Gain ________________________ in a narrow band amplifier with regenerative feedback.



REP4-1327

Figure 38-10. Double Tuned Transformer Response Curves

Refer to figure 38-10 for questions 10 through 12.

10. Select the curve which identifies undercoupling. ________________________

11. Select the curve which identifies overcoupling. ________________________

12. Select the curve which identifies critical coupling. ________________________

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CONFIRM YOUR ANSWERS.

ANSWERS TO A:

1. narrower
2. selectivity increases
3. C1 and T1 primary
4. secondary of T1
5. improve selectivity
6. False
7. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. C1 open
2. T2 primary open; C5 short; R4 open
3. C4 or T2 primary shorted
4. T1 primary open or shorted; C1 shorted; T2 secondary open or shorted
5. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. True
2. increased selectivity and sensitivity
3. high, low
4. True
5. a. Primary to secondary coupling coefficient
   b. The Q of the circuit
   c. Mutual inductance
6. loose
7. #3
8. #2
9. overcoupling
10. #2 - critical coupling
11. False

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1. feedback
2. regenerative, degenerative
3. degenerative
4. regenerative
5. regenerative
6. unilateralization
7. unilateralization or neutralization
8. regenerative

If you missed ANY questions, review the material before you continue.

ANSWERS TO LAB EXERCISE 1:

1. There was no signal output at TP106 on the oscilloscope.

2. The open T1 primary prevents the input signal from reaching the amplifier part of the circuit, but it does not interrupt DC path. Near normal measurements are, therefore, read at V_{CC} (TP105) and all points on the transistor.

ANSWERS TO LAB EXERCISE 2:

1. The voltage at TP102 actually drops to zero. When the secondary of T1 is open, there is no path for current to flow. Normally, the base current flows from ground, through R103, through Q101 emitter to base, through T101 secondary, through R101 and R102 to V_{CC}. If any of these components are open, there will be no current and no voltage at TP102.

2. With no current flowing there will be no voltage dropped across R103 and so TP104 will be at ground potential.

ANSWERS TO LAB EXERCISE 3:

1. When the emitter is open, the base voltage at TP102 increases and the emitter voltage at TP104 drops to zero. All of the voltage will be dropped across the open emitter, so a point between the emitter and V_{CC} will measure high (TP102), and a point between the emitter and ground will measure zero (TP104).

ANSWERS TO LAB EXERCISE 4:

1. The collector voltage at TP103 measures 8 volts (V_{CC}).

2. The current path between the collector and V_{CC} is broken and, as no current can flow because of the open collector, the voltage at TP103 will be maximum.

3. Base and emitter voltages dropped very low because the main current path through the collector has been broken.

ANSWERS TO LAB EXERCISE 5:

1. Base, collector, and emitter voltages all drop.

2. Collector voltage at TP103. This indicates a break between TP103 and V_{CC}. The only component in this path is the primary of T102.

ANSWERS TO MODULE SELF-CHECK:

1. C14, C15
2. regenerative
3. True
4. R_u, C_u
5. regenerative
6. C
7. True
8. increases
9. increases
10. A
11. D
12. B

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-39

Technical Training

Electronic Principles Department

ELECTRONIC PRINCIPLES

MODULE 39

SOLID STATE WIDEBAND AMPLIFIERS

1 May 1974

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

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Electronic Principles Department
Keesler Air Force Base, Mississippi

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1 May 1974

ELECTRONIC PRINCIPLES MODULE 39

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, references to other resources you may study, enabling you to satisfy the learning objectives.

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Supersedes KEP-GP-39, 9 November 1973. Present supplies will be used.

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SOLID STATE WIDEBAND AMPLIFIERS

1. SCOPE. Wideband amplifiers are those which amplify non-sinusoidal signals such as square, rectangular, sawtooth, and trapezoidal waves. These waves, which are used in television and radar equipment, consist of a fundamental frequency with a large number of harmonics. The wide range of frequencies contained in these signals makes it necessary to use amplifiers with a large bandpass. This chapter discusses square wave characteristics and methods of increasing the bandpass of amplifiers.

2. OBJECTIVES. Upon completion of this module, you should be able to satisfy the following objectives:

a. Given a pictorial diagram of a square wave and a list of statements, select the ones that identify the parts of the wave which contain

(1) high frequencies.

(2) low frequencies.

b. Given a list of statements, select the one which indicates the purpose of stagger-tuning amplifier stages.

c. Given a trainer having a solid state wideband amplifier, a square wave input, schematic diagram, and oscilloscope, draw the output waveshape indicating areas of low and high frequency distortion.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

NOTES

SOLID STATE WIDEBAND AMPLIFIERS

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

LABORATORY EXERCISE:

Laboratory Exercise 39-1, Solid State Wideband Amplifiers

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

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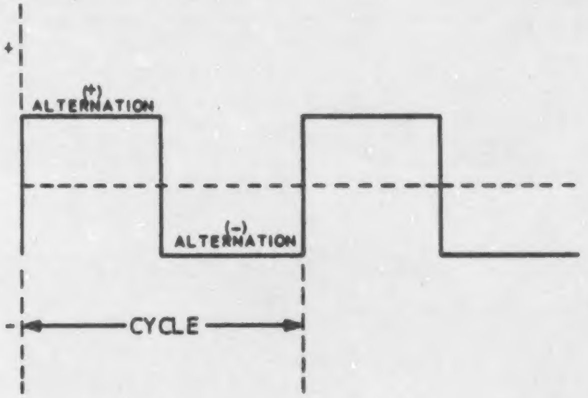
SOLID STATE WIDEBAND AMPLIFIERS

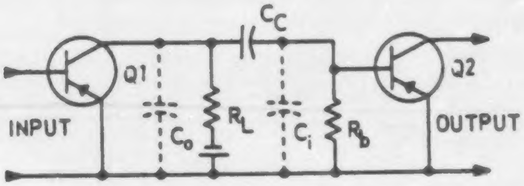
A very important factor in some applications of amplifiers is the ability to amplify non-sinusoidal signals. These include sawtooth, trapezoidal, and square waves. They consist of some fundamental frequency plus a large number of harmonics. To faithfully reproduce the signal, an amplifier must amplify the fundamental and all harmonics equally. This type of amplifier is called a wideband or video amplifier. Television or video signals are usually square or rectangular waves. A square wave consists of a fundamental frequency plus an infinite number of odd harmonics. This means that an amplifier must be able to amplify a wide range of frequencies in order to reproduce a square wave. Figure 1 represents a square wave and shows its different dimensions.



REP4-1254

Figure 1. Square Wave

The vertical leading and trailing edges of the wave contain the high frequencies. The flat tops and bottoms contain low frequencies. The frequency range of a video amplifier (typical wideband amplifier) must be from about 10 hertz to around 4 megahertz. Two frequency resqonse limitations must be overcome before a standard amplifier can be used for wideband amplification. Figure 2 shows the limiting factor of such an amplifier. The low frequency response is limited by C_C. The reactance of C_C increases as frequency decreases.



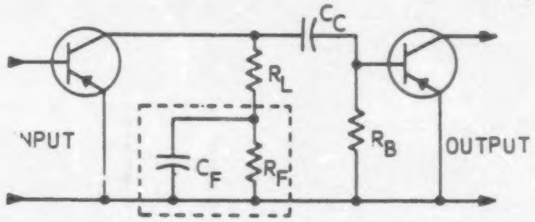
REP4-1253

Figure 2. RC Coupled Amplifier Showing Capacitive Effect at High Frequencies

DIGEST

Since C_C is in series, it drops more voltage at low frequencies leaving less to be applied as an input to Q2. High frequency response is limited by the dotted capacitances C_o and C_i. C_o represents the output and stray capacitance of Q1 and C_i is the input capacitance of Q2. As frequency increases, the reactance of C_o and C_i decrease, causing a loss of gain at high frequencies.

There are several ways to increase the frequency response of an amplifier so that it can process wideband signals successfully. One way is to decrease the size of the collector load resistor. This decreases the gain overall, but at the same time increases frequency response at both the high and low end of the band. A method of increasing the low frequency response is to increase the size of the coupling capacitor. Another way to increase low frequency response is to add a low frequency compensating network as shown in figure 3. R_F and C_F form a filter network which increases the gain at low frequencies only.



REP4-1255

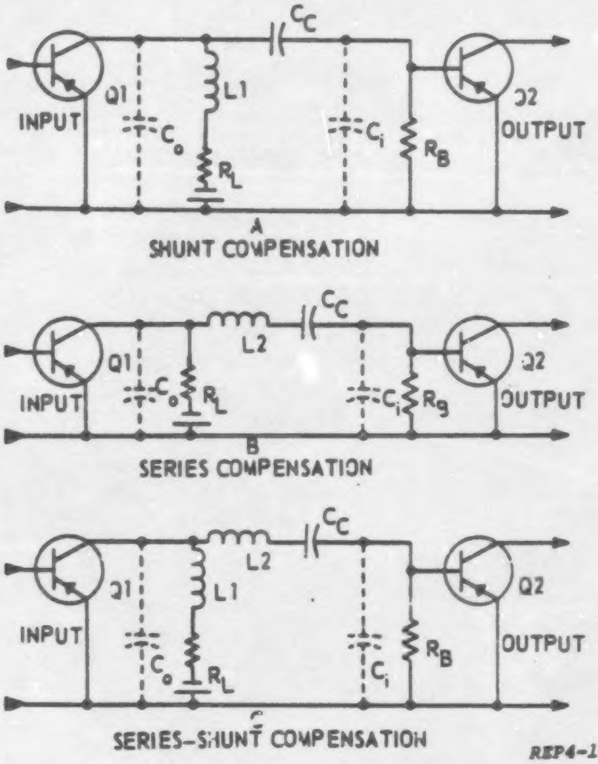
Figure 3. Wideband Amplifier, Low Frequency Compensation

At high frequencies, C_F is nearly a short and neither it nor R_F is in the circuit. However, at low frequencies, C_F is a large reactance. This large reactance is in parallel with R_F and both are in series with R_L, which increases the collector load resistance and gain at low frequencies.

A way to increase high frequency response of an amplifier is through the use of shunt and series peaking coils. Figure 4 shows how these coils are placed in the circuit. L1 (figure 4A) is in shunt with the signal path and C_o and forms a parallel resonant circuit with C_o and C_i (C_C is a short at high frequencies). A characteristic of a parallel tank circuit is high impedance. Without L1, C_o provides a low impedance path to ground. With L1, the parallel tank is a high impedance and therefore, the gain at high frequencies is increased.

L2 (figure 4B) is a series peaking coil. It is in series with the signal and forms a series resonant circuit with C_i (C_C is a short at high frequencies). The characteristics of a series tank circuit are low overall impedance, high current, and high voltage across either reactance. The series tank causes a high voltage across C_i at high frequencies, and again, the gain at these frequencies is increased. Figure 4C shows the use of both series and shunt high frequency compensation.

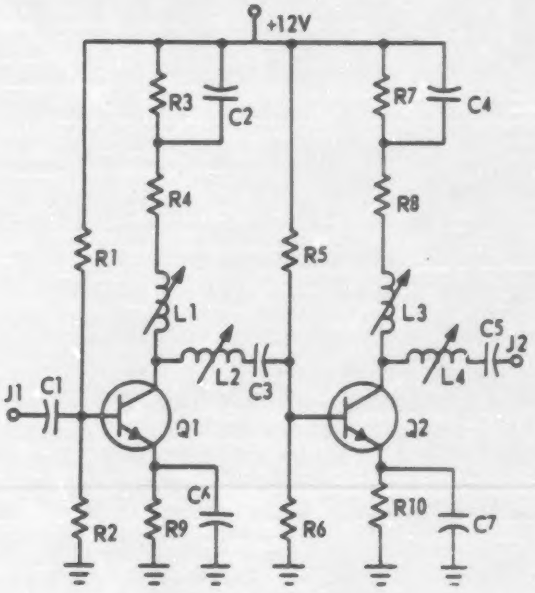
Figure 5 shows a fully compensated wideband amplifier. Collector loads R4 and R8 are small to increase overall frequency response. Coupling capacitor C1, C3, and C5 are large to increase low frequency response. Low frequency compensating networks R3-C2 and R7-C4 also increase low frequency response. Shunt peaking coils L1 and L3 and series peaking coils L2 and L4 increase high frequency response.



CC
L1
Q1
INPUT
Co
RL
Ci
RB
Q2
OUTPUT
A
SHUNT COMPENSATION
L2
CC
Q1
Co
RL
INPUT
Ci
RB
Q2
OUTPUT
B
SERIES COMPENSATION
L2
CC
L1
Q1
INPUT
Co
RL
Ci
RB
Q2
OUTPUT
C
SERIES-SHUNT COMPENSATION

REP4-1256

Figure 4. Wideband Amplifier, High Frequency Compensation



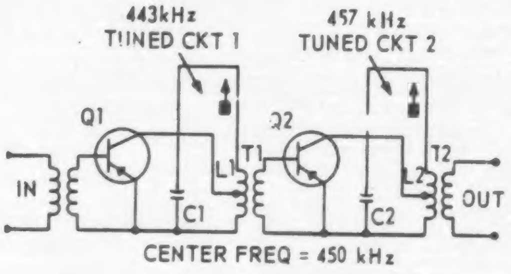
+12V
R3
C2
R7
C4
R4
R8
R1
R5
L1
L3
C5
J2
L2
C3
L4
J1
C1
Q1
Q2
C6
R2
R9
R6
R10
C7

REP4-1259

Figure 5. Compensated Wideband Amplifier

DIGEST

Another way to increase the bandwidth of amplifiers is through the use of STAGGER tuning. In this method, one transformer-coupled RF stage is tuned above the desired center frequency and one below. The resultant bandwidth is greater than if each stage were tuned to the center frequency. Figure 6 is a simplified schematic of two stages set up for stagger tuning. The center frequency is 450 kHz. L1 and C1 are tuned to 443 kHz. The output tank (L2-C2) is tuned to 457 kHz. The resultant bandwidth for both stages is greater than it would be if the tuned circuits were all tuned to the center frequency.



REP4-1258

Figure 6. Staggered Pair RF Amplifier (Simplified Schematic)

In troubleshooting a two-stage, fully compensated wideband amplifier, we will discuss only those faults which could cause problems with either the low or high frequency gain of the circuit. The waveshapes shown in figure 7 indicate the results of shorted or opened frequency compensating components. Use figure 7 in conjunction with figure 5. Part A shows the square wave input and part B is the ideal amplified output. The first waveshape in part C is labeled LOW FREQUENCY LOSS and indicates a lack of gain at low frequencies. R3, R7, C2, or C4 could be shorted. The second wave in part C shows increased gain at high frequencies indicating C2 or C4 open. The first wave in part D is the result of a shorted peaking coil (L1, L2, L3, or L4). In many cases, the peaking coils are tunable and can be maladjusted. The results of maladjusted peaking coils are shown in the second waveshape in part D.

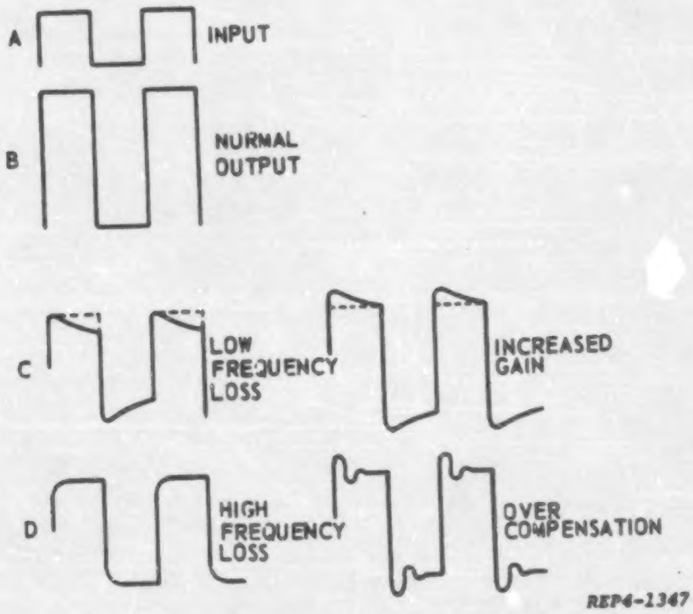

A
INPUT
B
NORMAL OUTPUT
C
LOW FREQUENCY LOSS
INCREASED GAIN
D
HIGH FREQUENCY LOSS
OVER COMPENSATION
REP4-1347

Figure 7. Wideband Amplifier Waveforms

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

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ADJUNCT GUIDE

SOLID STATE WIDE BAND AMPLIFIERS

INSTRUCTIONS:

Study the referenced material as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the page following the questions.

If you experience any difficulty, contact your instructor.

Turn the page and begin the program.

ADJUNCT GUIDE

In previous modules your studies were mostly associated with devices dealing with sinusoidal signals, which vary in proportion to the sine of an angle or time function. These signals were related to certain frequencies which were grouped in a relatively narrow frequency spectrum and amplified by circuits designed to pass only this narrow bandwidth.

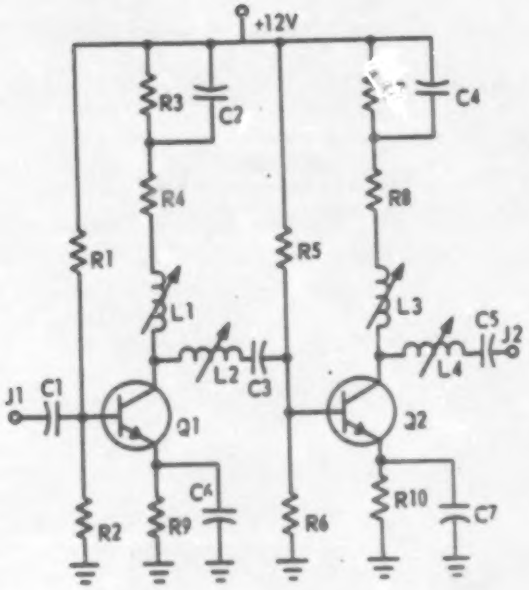
In this module you will be studying circuits with the ability to amplify nonsinusoidal signals as well. These signals do not vary at a sine wave rate and have a large number of harmonics such as those generated by timing and sweep circuits. The type of amplifiers used for these signals are classified as wide band or video amplifiers which must have the capability of amplifying an extremely wide spectrum of frequencies.

Video amplifiers are commonly associated with electronic systems which present some type of display such as found in radar and T.V. systems.

A. Turn to the Student Text, Volume V, and read paragraphs 7-1 through 7-19. Return to this page and answer the following questions.

1. A periodic wave which alternately assumes one of two fixed values, one positive and the other negative, is the definition for a ______________________.
2. The sides of a square wave represent the ____________________ frequencies.
3. The tops and bottoms (flat portions) of a square wave represent the ____________________ frequencies.
4. A square wave is composed of a fundamental frequency and an infinite number of ____________________ harmonics.
5. What is a typical frequency range for a video amplifier? ______________
6. One means of obtaining a wide bandwidth for a video amplifier is to use a ____________________ load resistor.
7. How is gain affected by using a small load resistor to obtain a wide bandwidth for a video amplifier? ______________________________
8. Name two methods used to extend the high frequency portion of a response curve in a video amplifier? ______________________________
9. Referring to figure 5, name the high frequency compensating components associated with Q1. ______________________________
10. Name the low frequency compensating components associated with Q1 in figure 8.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.



REP4-1259

Figure 8. Compensated Wide Band Amplifier

B. Turn to the Student Text, Volume V, and read paragraphs 7-20 through 7-33. Return to this page and answer the following questions.

1. Stagger tuning is another method used to increase the ____________________ of amplifiers.

2. When stagger tuning two transformer-coupled RF stages, the two circuits are tuned above and below the ____________________ frequency.

3. Stagger tuning amplifiers will give a wider bandwidth than tuning each circuit to the same frequency.

   (TRUE) (FALSE).

4. What is accomplished by the use of low frequency compensation networks in the operation of a wide band amplifier? ____________________

   ____

5. What effect does the low frequency compensation network have on the operation of a wide band amplifier at high frequencies? ____________________

   ____

   ____

ADJUNCT GUIDE

ANSWERS TO A:

1. square wave
2. high
3. low
4. odd
5. 10 Hz to 4 MHz
6. small
7. gain is reduced
8. shunt and series compensation
9. L1 L2
10. R3, C2

If you missed ANY questions, review the material before you continue.

---

6. Referring to figure 9, given the input waveform (A) and the normal output waveform (B) of a wide band amplifier, what type of problem would be indicated if wave form C was seen as the output wave shape? ______________________

7. Referring to figure 9 and question 6, what type of problem would be indicated if waveform D was present at the output? ______________________

8. Referring to figure 8 and 9. If waveform D appeared as the output of figure 8, list the components and condition that could cause this malfunction. ______________________

9. The presence of waveform F (figure 9) at the output of figure 8 would indicate ______________________.

10. The presence of waveform E (figure 9) at the output of figure 8 would indicate a malfunction of which components? ______________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

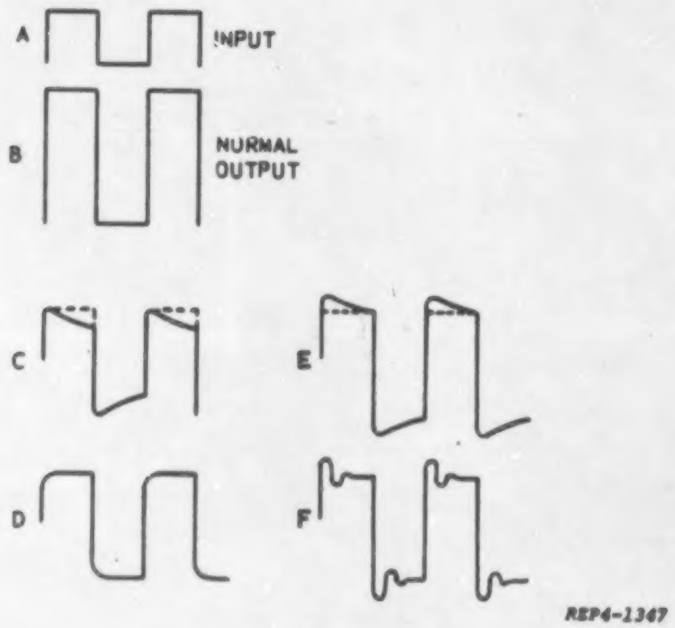

A
INPUT
B
NORMAL OUTPUT
C
D
E
F
REP4-1347

Figure 9. Wideband Amplifier Waveforms

NOTES

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ANSWERS TO B:

1. bandwidth
2. center
3. TRUE
4. eliminates low frequency distortion
5. no effect
6. low frequency loss
7. high frequency loss
8. shorted L1, L2, L3 or L4.
9. high frequency overcompensation
10. C2 or C4 open

If you missed ANY questions, review the material before you continue.

C. Turn to Laboratory Exercise 39-1 and complete all sections before returning to this page. If you have any difficulty contact your instructor. This exercise will enable you to apply the theory of wideband amplifier circuits you have just studied by actual performance and observation on an operational circuit. After performing the laboratory exercise return to this page.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 39-1

SOLID STATE WIDEBAND AMPLIFIERS

OBJECTIVES: Given a trainer having a solid state wideband amplifier, a square wave input, schematic diagram, and oscilloscope, draw the output waveshape indicating areas of low and high frequency distortion.

EQUIPMENT:

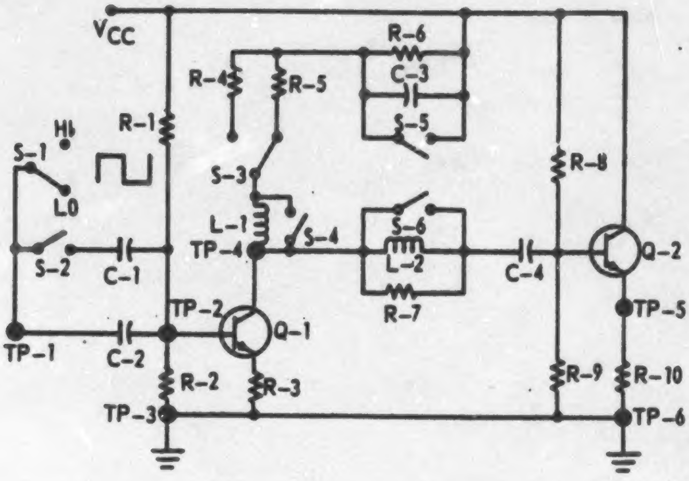
1. Video Amplifier Trainer (5648).
2. Oscilloscope (LA-261).

REFERENCE: Student Text, Volume V, Chapter 7.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Analysis of the trainer.
   - a. The wideband amplifier trainer schematic diagram is shown in figure 10.
   - b. The trainer incorporates a built-in square wave signal generator, with switch S1 for selecting HI or LO frequency signal inputs.
   - c. The trainer provides switching arrangements for insertion of high and low frequency compensating circuits.


VCC
R-1
R-2
R-3
R-4
R-5
R-6
R-7
R-8
R-9
R-10
C-1
C-2
C-3
C-4
L-1
L-2
S-1
S-2
S-3
S-4
S-5
S-6
HI
LO
TP-1
TP-2
TP-3
TP-4
TP-5
TP-6
Q-1
Q-2

REP4-1407

Figure 10. Video Amplifier Trainer

2. Preparation of the equipment:

a. Trainer

CONTROL	POSITION
(1) S1	LO
(2) S2	LEFT
(3) S3	RIGHT
(4) S4	UP
(5) S5	RIGHT
(6) S6	RIGHT

b. Oscilloscope to trainer:

(1) Ground oscilloscope to trainer TP6.

(2) Connect A Channel probe to trainer TP1.

(3) Connect B Channel probe to trainer TP2.

(4) Connect oscilloscope trigger input to trainer TP5.

3. **Activity:**

a. With switch S1 in the LO position, the trainer is set up to function as an uncompensated low frequency wideband amplifier. The following steps will show the effects of the low frequency compensating circuits on the output signal.

(1) With switch S2 in the left (open) position, observe and draw the waveforms that appear at TP1 and TP2 on graphs #1 and #2 respectively.

(2) By comparison of the two signals at TP1 and TP 2, what effect does the coupling capacitor C2 have on the input signal? ____________________

____

(3) Change switch S2 to the right (closed) position. Observe and draw the waveform that now appears at TP2 on graph #3.

(a) What effect did closing switch S2 have on the coupling capacitance?

____

(b) What effect did this have on capacitive reactance? ____________________

____

(c) By comparison of the waveforms in graph #3 and #2, what effect would using a large input coupling capacitance have on the low frequency response? ____________________

(4) Remove the trigger input probe from TP5 and connect the B Channel probe to TP5.

(a) Observe and draw the waveform appearing at TP5 on graph #4.

(b) The slope on the top and bottom of the output signal indicates what type of distortion? ____________________

(c) What is the cause of this type of distortion?

(5) Change switch S5 to the left (open) position. Observe and draw the resulting output waveshapes on graph #5. What is the effect on the output signal with C3 and R6 added to the circuit? ____________________

CONSULT YOUR INSTRUCTOR FOR VERIFICATION OF YOUR ANSWERS.

(6) Change switch S3 to the left (R4) position. Observe and draw the resulting output waveform on graph #6.

(a) What effect did changing the load resistor from 10 k to 5.1 k have on the output signal frequency response? ______________________

(b) What effect did this change have on the output signal gain? ______________________

b. Change switch S1 to the HI position. This will allow the trainer to function as an uncompensated high frequency amplifier. The following steps will show the effects of the high frequency compensating circuits on the output signals.

(1) With the B Channel probe connected to TP5, adjust the oscilloscope to observe two cycles of the signal and draw the output waveform on graph #7.

(2) Change switch S4 to the down (open) position. Observe and draw the resulting output waveshape on graph #8.

(a) With L1 added to the circuit, which part of the waveform is affected? ______________________

(b) What is the effect on the high frequency response when a shunt peaking coil is added to the circuit? ______________________

(3) Change switch S6 to the left (open) position. Observe and draw the resulting output waveform on graph #9.

(a) With L2 added to the circuit, which part of the waveform is affected? ______________________

(b) What is the effect on the high frequency response when a series peaking coil is added to the circuit? ______________________

c. Set up the trainer to function as a low frequency, uncompensated, wideband amplifier.

(1) Using the oscilloscope measure the following:

(a) Input signal voltage (Pk/Pk) = ______________________

(b) Output signal voltage (Pk/Pk) = ______________________

(c) Amplifier gain = ______________________

CONSULT YOUR INSTRUCTOR FOR VERIFICATION OF YOUR ANSWERS.

(2) Change the appropriate controls to allow the trainer to function as a compensated low frequency wideband amplifier and measure the following:

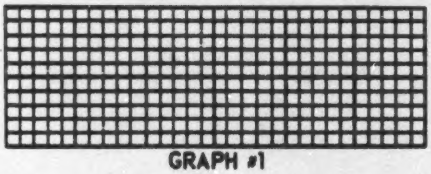
(a) Input signal voltage (Pk/Pk) ______________________

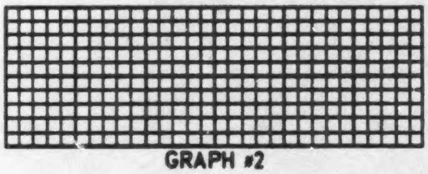
(b) Output signal voltage (Pk/Pk) ______________________

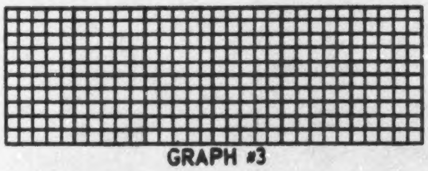
(c) Amplifier gain ______________________

(3) In an uncompensated amplifier, the output signal gain would be ________ , and the frequency distortion would be ____________________ .

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.


GRAPH #1


GRAPH #2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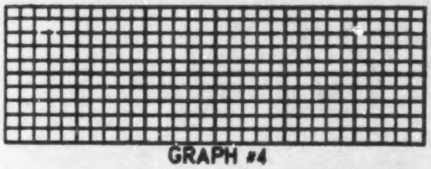
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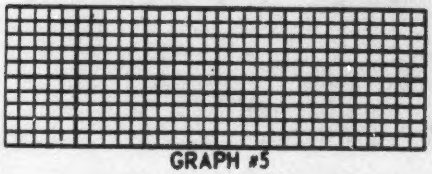
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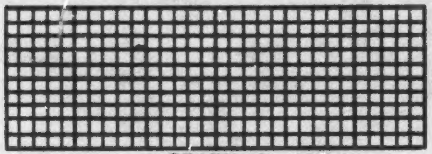
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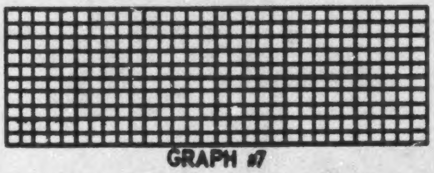
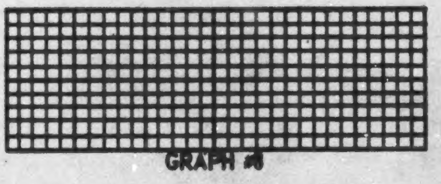

GRAPH #7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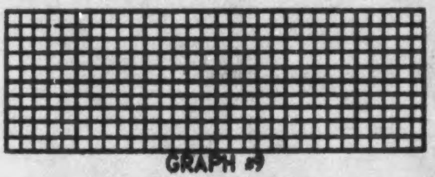
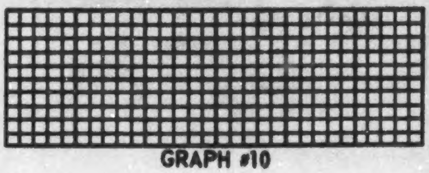
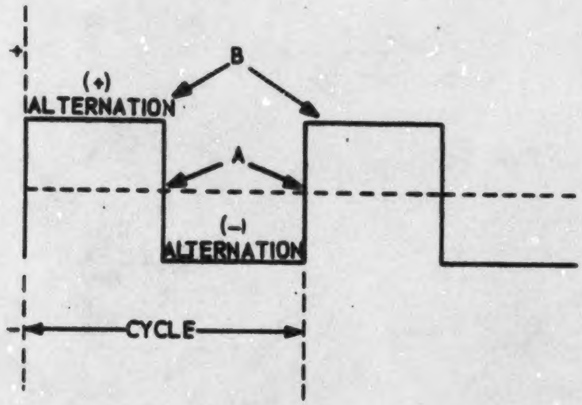

GRAPH #9


GRAPH #10

SOLID STATE WIDEBAND AMPLIFIERS

QUESTIONS



REP4-1408

Figure 11. Square Wave

1. Referring to the square wave in figure 11, what frequency range does that portion of the wave labeled A represent?

2. The portion of the square wave labeled B in figure 11 represents what frequency range?

3. In figure 12, waveform A and B represent the normal input and output of a wideband amplifier, what would wave form C indicate if it appeared as the output instead of waveform B.

4. Referring to question 3. What would waveform D indicate if it appeared as the output instead of waveform B.

5. The purpose of stagger tuning amplifier stages is to

   a. increase bandwidth

   b. increase selectivity

   c. increase gain

   d. decrease bandwidth

6. In a wideband amplifier what frequencies do the coupling capacitors attenuate?

7. In a wideband amplifier with high and low frequency compensation circuits, the compensation circuits operate independently of each other. (TRUE) (FALSE)

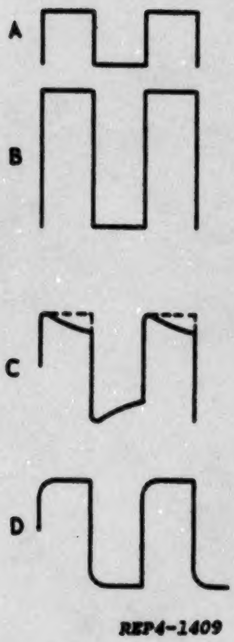


Figure 12

8. In a wideband amplifier, the bandwidth will ____________ when the load resistor is decreased.

9. What is the purpose of shunt and series peaking coils in wideband amplifiers?

10. What is the disadvantage of decreasing RL to increase bandwidth in a wideband amplifier?

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

NOTES

ANSWERS TO QUESTIONS:

1. high frequencies
2. low frequencies
3. low frequency loss
4. high frequency loss
5. A
6. low frequencies
7. TRUE
8. increase
9. high frequency compensation
10. reduced gain

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOUCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FUR FURTHER INSTRUCTIONS.

ATC GP 3AQR3X020-X

Prepared by Keesler TTC
KEP-GP-40

Technical Training

Electronic Principles (Modular Self-Paced)

Module 40

SATURABLE REACTORS AND MAGNETIC AMPLIFIERS

October 1975

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

ATC Keesler 6-2046

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Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-40
October 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 40

SATURABLE REACTORS AND MAGNETIC AMPLIFIERS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

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Adjunct Guide	1
Module Self-Check	3
Answers	7

OVERVIEW

1. SCOPE: Saturable reactors are inductors with special characteristics and are used in power control devices. Magnetic amplifiers use saturable reactors and other components to control power. This chapter discusses saturable reactor characteristics, control functions, and their use in magnetic amplifiers.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives.

a. Given the drawing of a hysteresis curve for a saturable reactor, identify the:

(1) Magnetizing force.

(2) Coercive force.

(3) Residual magnetism.

(4) Flux density.

(5) Point of saturation.

b. Given the schematic drawing of a single winding saturable reactor, AC line voltage, and saturating point, identify the output waveforms across the:

(1) Reactor winding.
(2) Load resistor.

c. Given a list of statements and the schematic diagram of a two winding saturable reactor circuit, select the statement(s) that describe(s):

(1) Control winding.
(2) Load winding.
(3) Load resistor.
(4) Control adjustment.
(5) AC line voltage.
(6) Control voltage.
(7) Output waveforms.

d. Using a schematic diagram and a given set of conditions, develop output waveforms for an electrically connected magnetic amplifier.

Supersedes KEP-GP-40, 1 May 1974. Present supplies will be used.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience and preference, any or all of the following.

READING MATERIALS:

Digest

Adjunct Guide with Student Text V

AUDIOVISUALS:

Television Lesson 30-701, Saturable Reactors

Television Lesson 30-702, Full Wave Magnetic Amplifier

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY. CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced material as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

In this module you will study amplifier circuits which handle large amounts of power and are generally associated with control functions. These circuits use the principles of saturable reactors and magnetic amplifiers. They are simple, rugged, efficient, reliable, and capable of providing large amounts of power.

A. Turn to the Student Text, Volume V, and read paragraphs 8-1 through 8-22. Return to this page and answer the following questions.

1. What are the two magnetic variables in a magnetic circuit?

a. ______________________

b. ______________________

2 The property which opposes the creation of magnetic flux within a coil is __________.

3. Core materials used in saturable reactors must be capable of producing ____________ values of flux density with ____________ values of magnetizing force.

4. The ratio which expresses the permeability of any material is referred to as the ______________________.

5. The magnetizing force required to cancel residual magnetism is called ____________.

6. The ideal hysteresis loop for saturable reactors is ____________ in shape and very ______________ in width.

7. When the core of a reactor is unsaturated the impedance of the reactor is __________.

8. At what point of operation of a saturable reactor is the line voltage impressed across the load resistor? ______________

9. What effect does increasing the magnetizing force have on a core that has already reached saturation? ______________________

10. The plotted cycle of magnetization of a saturable core is called a ______________.

CONFIRM YOUR ANSWERS.

B. Turn to the Student Text, Volume V, and read paragraphs 8-23 through 8-40. Return to this page and answer the following questions.

1. How is amplifier action obtained in a saturable reactor circuit? ________________

Refer to figure 40-1 for questions 2 through 7.

2. Which circuit establishes the time that core saturation occurs? ________________

3. Control current is increased when the arm of R_C is moved toward point ________.

4. Core saturation occurs faster when the control current is ____________________.

5. When the core saturates for a longer period of time, the average current delivered to the load ___________________________.

6. If the arm of R_C moved to position B, which of the waveshapes would represent the current delivered to the load?

____

7. If the arm of R_C moved to position A, which of the waveshapes would represent the current delivered to the load?

____

8. The purpose of having a high impedance control winding in a saturable reactor circuit is to reduce ____________________.

9. What is the purpose of using an iron core choke coil in the control circuit of a saturable reactor? ____________________

10. A magnetic amplifier cannot have more than two windings. (True) (False)

CONFIRM YOUR ANSWERS.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

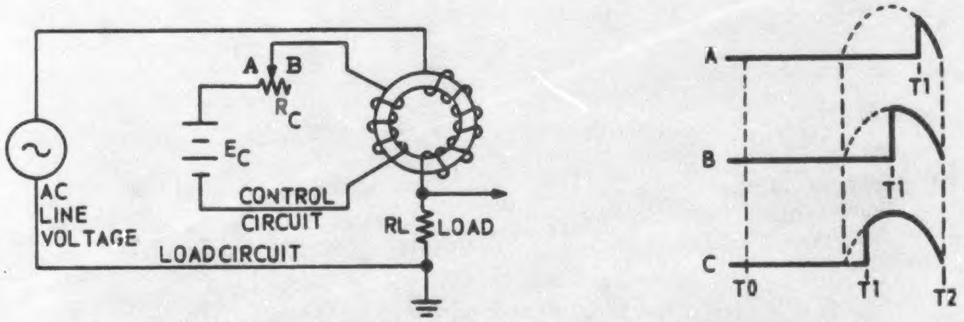


Figure 40-1. Saturable Reactor Circuit and Waveshapes

MODULE SELF-CHECK

Refer to figure 40-2 for questions 1 through 5.

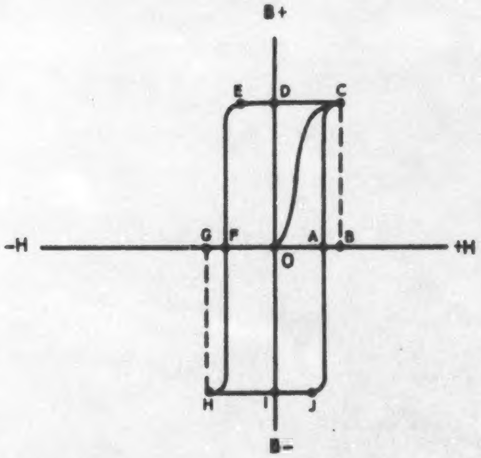


Figure 40-2. Hysteresis Loop

1. The magnetizing force required for saturation during the positive alternation of current can be represented by __________.

2. The coercive force can be represented by __________________________________.

3. The residual magnetism can be represented by __________________________.

4. Maximum flux density is reached at levels ____________ and ____________.

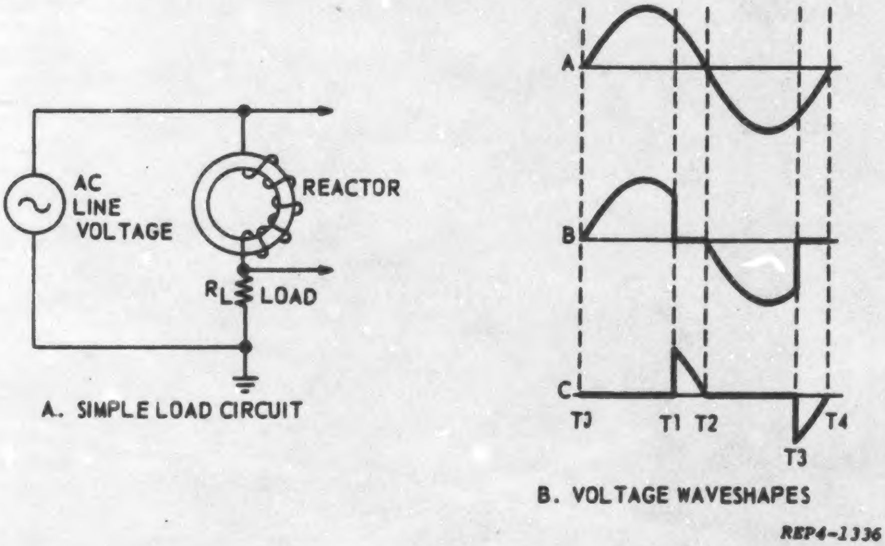
5. The initial points of saturation can be represented by __________________________.

6. Refer to figure 40-3 and identify the waveform across R_L.

A ______ B ______ C ______

7. What waveform would appear across the reactor in figure 40-3?

A ______ B ______ C ______



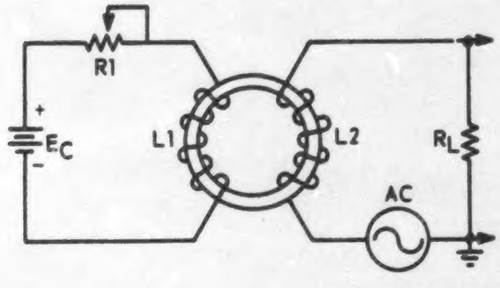
A. SIMPLE LOAD CIRCUIT

B. VOLTAGE WAVESHAPES

REP4-1336

Figure 40-3

Use figure 40-4 for questions 8 through 14.



REP4-1436

Figure 40-4

8. The control winding is:

a. L2.

b. L1.

c. R1.

d. R_L.

9. The load winding is:

a. L1.

b. L2.

c. R_L.

d. R1.

10. The load is represented by:

a. R1.

b. L1.

c. R_L.

d. E_C.

11. The control adjustment is:

a. R_L.

b. E_C.

c. L1.

d. R1.

12. The AC line is in:

a. series with the load and L1.

b. series with the load and L2.

c. parallel with the load and L2.

d. series with R1 and L1.

13. The control voltage is:

a. AC.

b. DC.

c. pulsating DC.

14. The voltage waveshape delivered to the load depends on:

a. The resistance of the load.

b. The AC voltage presented to the load.

c. The setting of R1.

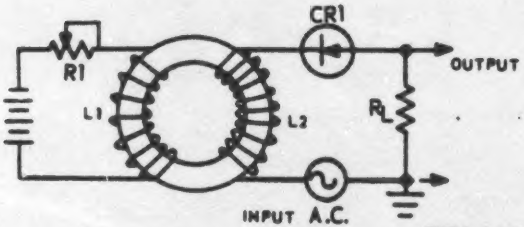
15. An amplifier which employs a saturable reactor as its amplifying device is called a

________________________________.

16. In a magnetic amplifier (small) (large) power changes in the control circuit can produce (small) (large) power changes in the load circuit.

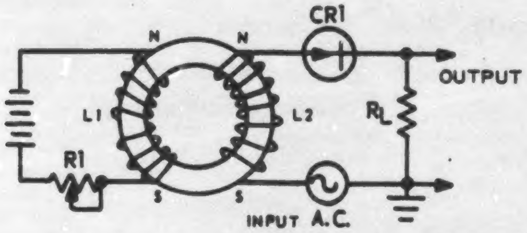
Column A

Column B


CR1
R1
L1
L2
R_L
OUTPUT
INPUT A.C.

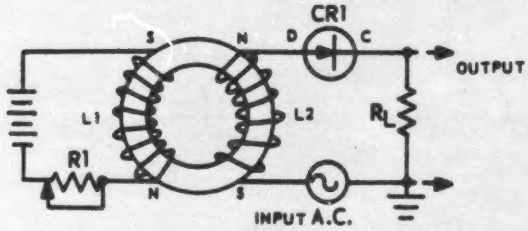
REP4-1342

(1) __________


CR1
N
N
L1
L2
R_L
OUTPUT
R1
S
S
INPUT A.C.

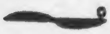
REP4-1343

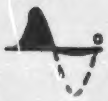
(2) __________

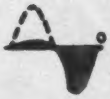

CR1
S
N
D
C
OUTPUT
L1
L2
R_L
R1
N
S
INPUT A.C.

REP4-1344

(3) __________

a. 

b. 

c. 

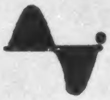
d. 

Figure 40-5

17. See figure 40-5 and match the output waveshapes of column B to the half wave magnetic amplifier circuits of column A.

Refer to figure 40-6 for questions 18 through 21.

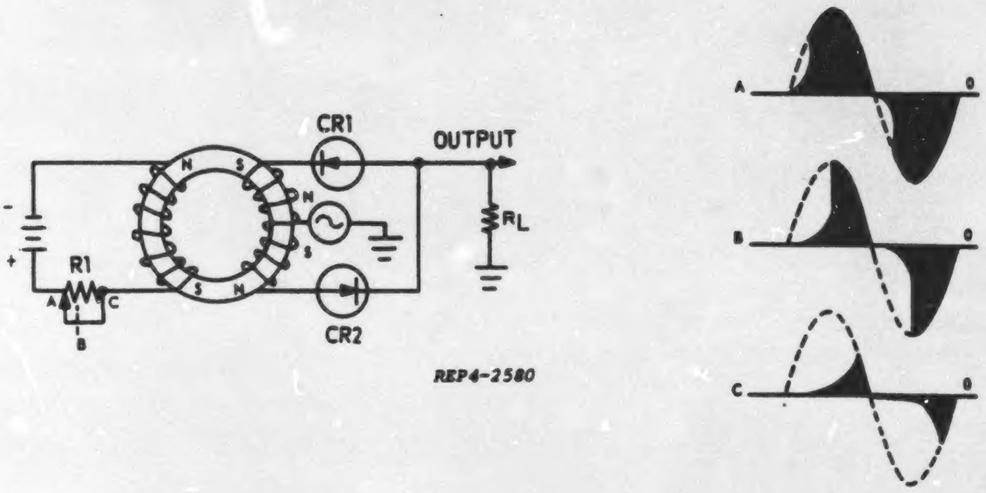

CR1
OUTPUT
N
S
N
S
S
N
R1
A
B
C
RL
CR2
REP4-2580
A
0
B
0
C
0

Figure 40-6

18. The circuit is a (half wave) (full wave) magnetic amplifier.

19. With the arm of R1 at point A the circuit will produce waveshape (A) (B) (C).

20. Moving the arm of R1 to point B will produce waveshape (A) (B) (C).

21. Moving the arm of R1 to point C will produce waveshape (A) (B) (C).

CONFIRM YOUR ANSWERS.

ANSWERS TO A:

1. a. magnetomotive force (MMF)

   b. flux (ø)

2. reluctance

3. high, low

4. B-H ratio

5. Coercive Force

6. rectangular, narrow

7. high

8. full saturation

9. none

10. hysteresis loop

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. a small power source controlling a large power source

2. control circuit

3. A

4. increased

5. increased

6. A

7. C

8. transformer action

9. to reduce transformer action

10. False

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. 0 - B

2. 0 - F, O-A

3. 0 - D, O-I

4. CDE & HIJ

5. C and H

6. C

7. B

8. b

9. b

10. c

11. d

12. b

13. b

14. c

15. magnetic amplifier

16. small, large

17. (1) c

    (2) a

    (3) b

18. full wave

19. A

20. B

21. C

HAVE YOU ANSWERED ALL THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.

ATC GP 3AQR3X020-X

Prepared by Keesler TTC
KEP-GP-41

Technical Training

Electronic Principles (Modular Self-Paced)

Module 41

SYNCHRO-SERVO SYSTEMS

October 1975

AIR TRAINING COMMAND

7-9

Designed For ATC Course Use

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Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-41
October 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 41

SYNCHRO-SERVO SYSTEMS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Title	Page
Overview	1
List of Resources	1
Adjunct Guide	1
Module Self-Check	5
Answers	10

OVERVIEW

1. SCOPE: Synchro-servo systems are used in control applications. These applications include antenna control, missile guidance and tracking, satellite tracking, gun laying, and automatic pilots. For example, small synchro devices used with amplifiers and motors make up a servo system to control the movements of a radar antenna weighing several tons. Here we discuss the basic operation of a synchro, servo amplifier, and servo control systems.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives.

a. Given a schematic diagram and a group of statements, select the statement that describes the operation of a synchro system.

b. Given the schematic diagram of a basic servo amplifier, identify the push-pull amplifier, the stabilization components, and the feedback components.

c. Given a block diagram and a group of statements, select the statement that describes the operation of a servo control system.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience and preference, any or all of the following.

READING MATERIALS:

Digest

Adjunct Guide with Student Text V

Supersedes KEP-GP-41, dated 1 June 1974. Stocks on hand will be used.

AUDIOVISUALS:

Television Lesson 30-418, Introduction to Servoamplifiers
Television Lesson 30-753, Synchros
Television Lesson 30-754, Servomechanisms

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY. CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

In this module you will study synchro-servo systems which are electromechanical systems used for transmitting mechanical positions from one point to another by electrical signals. In synchro-servo systems the control signals are generated by mechanical motion and position, and are related to the angular position of a shaft. Synchro-servo systems have a wide range of application. They are rugged and reliable but, like any equipment, will occasionally need repair.

A. Turn to the Student Text, Volume V, and read paragraphs 9-1 through 9-27. Return to this page and answer the following questions.

1. What is the main difference between a synchro system and a servo system?

____

____

2. Synchros are devices which use DC voltages for rotor excitation. (True) (False)

3. Name the two components required to form a synchro system.

a. ______________________________

b. ______________________________

4. A synchro system uses three-phase voltage. (True) (False)

5. The device used to prevent undesirable oscillation in a synchro motor is an

______________________________.

6. In a synchro generator, what determines the phase and amplitude of the voltage induced in each stator winding?

____

____

7. What is the spacing between the three stator coils in a synchro generator?

____

____

8. What type of action takes place between the rotor and stator of a synchro generator?

____

____

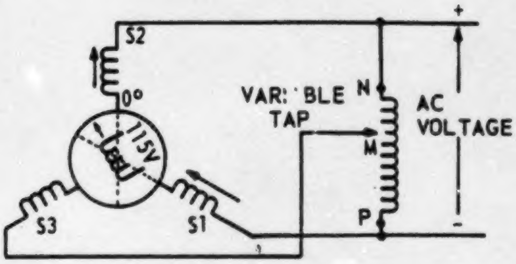
9. In a synchro system the (rotor) (stator) is connected to the AC power source.

10. A 360° rotation of a synchro generator rotor will cause the voltage in each stator winding to reach a maximum value (once) (twice) (three times).

CONFIRM YOUR ANSWERS.

B. Turn to the Student Text, Volume V, and read paragraphs 9-28 through 9-42. Return to this page and answer the following questions.

Refer to figure 41-1 for questions 1, 2, and 3.



REP4-1352

Figure 41-1

1. What is the maximum angular movement obtainable by the rotor when the variable tap is moved from position N to position P?

2. When the variable tap is at position N, what will be the angular position of the rotor?

3. What will be the angular position of the rotor when the variable tap is moved to position M?

4. In a normal synchro system, what determines the position of the generator rotor?

5. When the rotors of a synchro generator and motor are not in corresponding positions, the resulting torque will be exerted on both rotors. (True) (False)

Refer to figure 41-2 for questions 6 and 7.

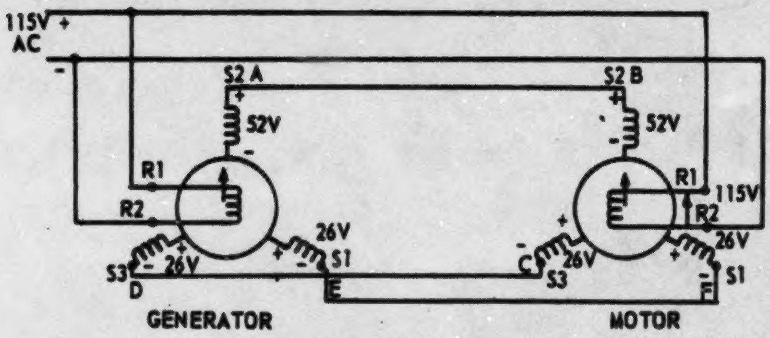
6. With the rotors of the generator and motor in the positions as shown, what will be the direction of current flow between the stator windings?

7. If the generator rotor is turned 30° counterclockwise, the induced voltage will cause current flow between the stator windings. List the correct sequence of current flow between each pair of windings.

8. Maximum torque is produced when the generator and motor rotors are ______ degrees apart.

9. Only one synchro motor may be connected to a synchro generator. (True) (False)

10. What is the main disadvantage of connecting too many motors to a single synchro generator?


115V +
AC
-
S2 A
+
52V
-
S2 B
+
52V
-
R1
R2
26V
S1
S3
26V
D
E
GENERATOR
R1
115V
R2
26V
C
26V
S3
S1
F
MOTOR

REP4-1361

Figure 41-2. Synchro System

CONFIRM YOUR ANSWERS.

C. Turn to the Student Text, Volume V, and read paragraphs 9-43 through 9-60. Return to this page and answer the following questions.

1. A servoamplifier combines what two functional stages?

a. ____________________

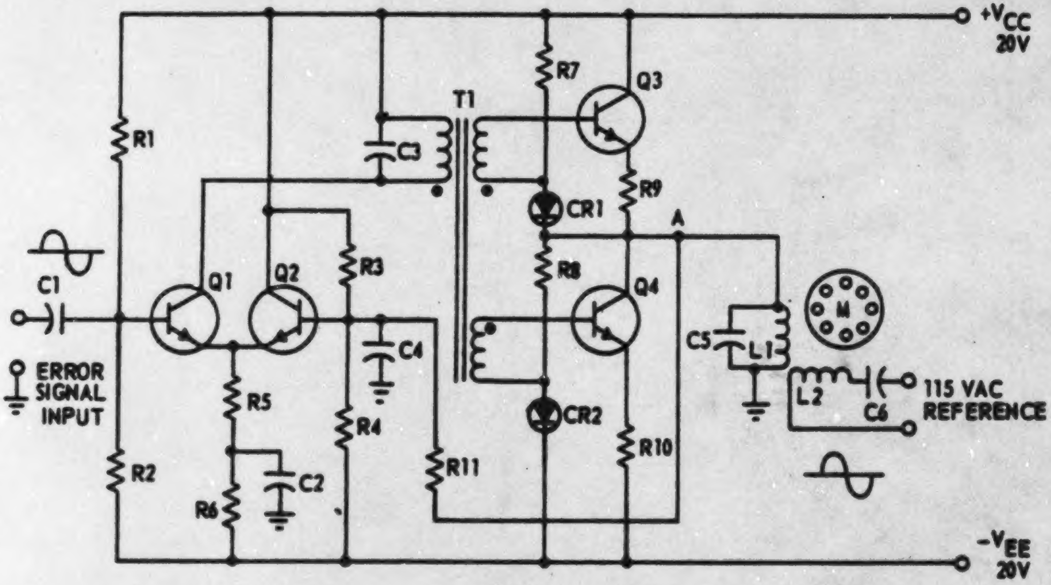
b. ____________________

2. In a servoamplifier system, the amplitude of the error voltage applied to the servomotor will determine the __________ of rotation of the servomotor.

3. The phase of the error voltage applied to the servomotor will determine the ________ of rotation of the servomotor.

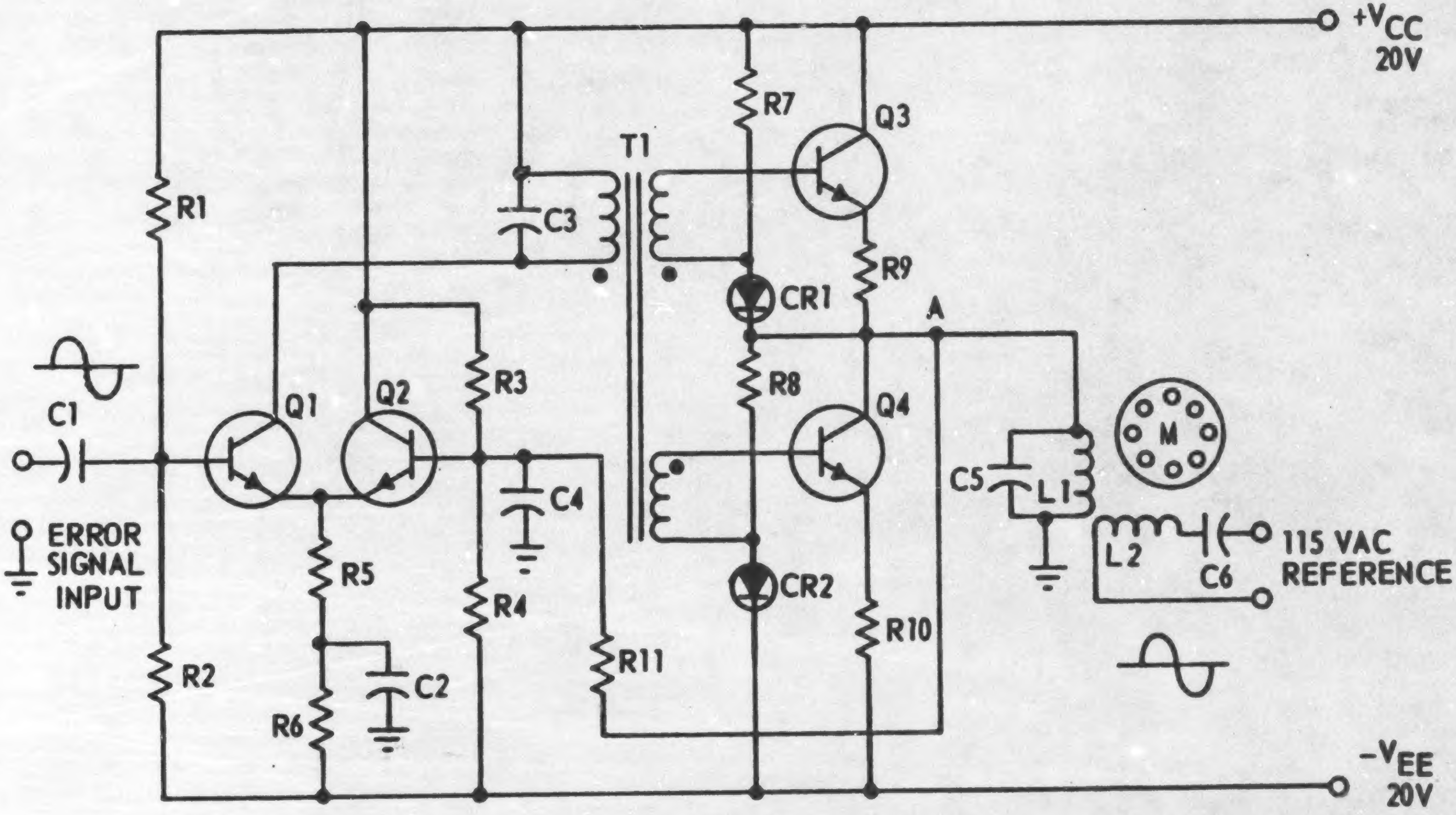
Refer to figure 41-3 for questions 4 through 9.

4. The error voltage applied to control winding L1 either leads or lags the voltage applied to reference winding L2 by ________ degrees.


+V$_{CC}$
20V
R7
Q3
T1
R1
C3
R9
CR1
A
C1
Q1
Q2
R3
R8
Q4
M
ERROR
SIGNAL
INPUT
C4
C5
L1
L2
C6
115 VAC
REFERENCE
R5
R4
CR2
R10
R11
R2
C2
R6
-V$_{EE}$
20V

REP4-1373

Figure 41-3. Servoamplifier


+V$_{CC}$
20V
R7
Q3
T1
C3
R1
R9
CR1
A
R3
Q1
Q2
C1
Q4
R8
C5
L1
M
C4
ERROR
SIGNAL
INPUT
R5
R4
CR2
115 VAC
REFERENCE
L2
C6
R10
R11
R2
R6
C2
-V$_{EE}$
20V

REP4-1373

Figure 41-3. Servoamplifier

5. What is the purpose of diodes CR1 and CR2? ____________________

6. What is the phase relation of the error signals applied to the bases of Q3 and Q4?

____

7. What type of amplifier would the combination of Q3 and Q4 be classified as?

____

8. The circuit composed of Q1 and Q2 is classified as what type of circuit?

____

9. When will the output of the differential amplifier be zero? ____________________

____

10. The gain of a servoamplifier should be the same for starting the motor as it is for running it. (True) (False)

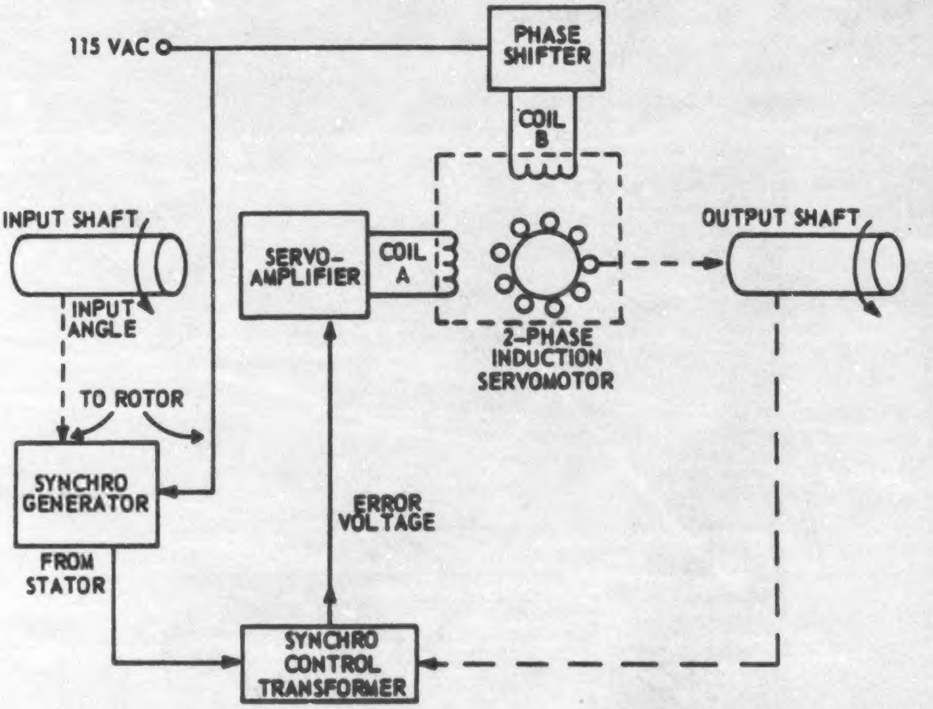
Use figure 41-4 for questions 11 through 15.

11. The block diagram represents what is commonly called a ____________ system.

12. Turning the input shaft produces a/an (electrical) (mechanical) signal at the rotor of the synchro control transformer.

13. The rotor of the control transformer is mechanically positioned by the (input) (output) shaft.

14. AC line excitation is applied to the rotors of both the synchro generator and synchro motor. (True) (False)


115 VAC
PHASE SHIFTER
COIL B
INPUT SHAFT
INPUT ANGLE
SERVO-AMPLIFIER
COIL A
OUTPUT SHAFT
2-PHASE INDUCTION SERVOMOTOR
TO ROTOR
SYNCHRO GENERATOR
FROM STATOR
ERROR VOLTAGE
SYNCHRO CONTROL TRANSFORMER

REP4-1374

Figure 41-4

15. The angular difference between the input and output shafts (determines) (is determined by) the signal on coil A.

CONFIRM YOUR ANSWERS.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

1. Select the statement that describes the operation of a synchro.

__a. Inductive devices are capable of converting angular inputs to electrical outputs or electrical inputs to angular outputs.

__b. A synchro is a three-phase low torque device.

__c. Synchro systems include a power amplifier.

__d. Synchros can change low torque inputs into high torque outputs.

Refer to figure 41-5 for questions 2, 3, and 4.

2. In the system shown, an inertial damper:

__a. Controls the speed of the motor.

__b. Prevents oscillations of the motor.

__c. Maintains alignment of the stators.

__d. Prevents reverse torque of the generator.

3. There is no torque on the motor because:

__a. There are no rotor currents.

__b. Rotor currents are out of phase.

__c. Stator currents are in phase.

__d. There are no stator currents.

4. If the generator rotor is turned slightly clockwise, the voltages at points:

__a. A, E, and D would decrease.

__b. A and E would increase and D would decrease.

__c. A and E would decrease and D would increase.

__d. A, E, and D would increase.

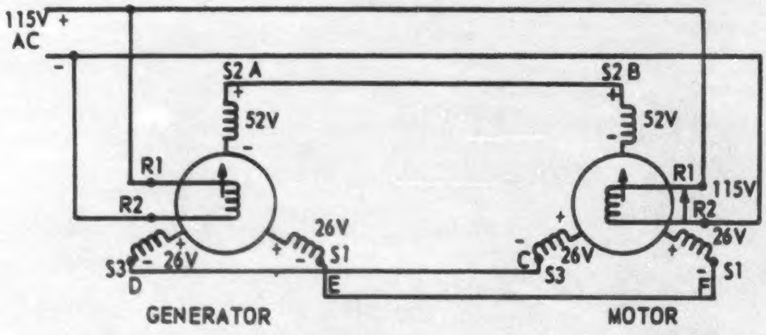
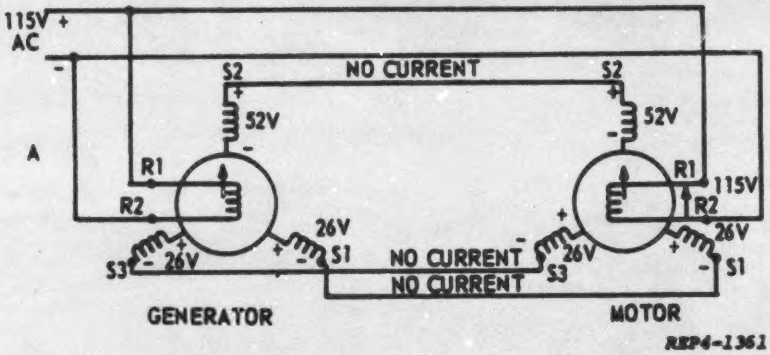
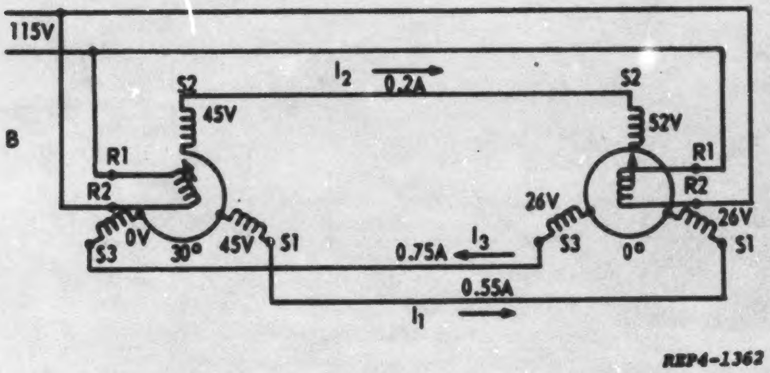


Figure 41-5


115V +
AC
-
A
S2
NO CURRENT
S2
52V
52V
R1
R2
R1
115V
R2
26V
26V
26V
26V
S3
S1
NO CURRENT
NO CURRENT
S3
S1
GENERATOR
MOTOR
REP4-1361

0° Difference in Rotors


115V
B
I_2 0.2A
S2
45V
S2
52V
R1
R2
R1
R2
26V
26V
0V
30°
45V
S3
S1
0.75A
I_3
S3
0°
S1
0.55A
I_1
REP4-1362

30° Difference in Rotors

Figure 41-6. Synchro System

5. The stator voltages indicated in figure 41-6A are:

__a. Steady DC.

__b. Pulsating DC.

__c. Peak AC.

__d. Effective AC.

6. The direction(s) of the torque exerted in figure 41-6B with the conditions indicated is/are:

__a. Motor and generator clockwise.

__b. Motor and generator counterclockwise.

__c. Motor clockwise and generator counterclockwise.

__d. Motor counterclockwise and generator clockwise.

7. A limiting factor of a basic synchro system is:

__a. Each motor requires a separate generator.

__b. The requirement for three-phase power.

__c. The maximum torque capability.

__d. Generators require external inputs.

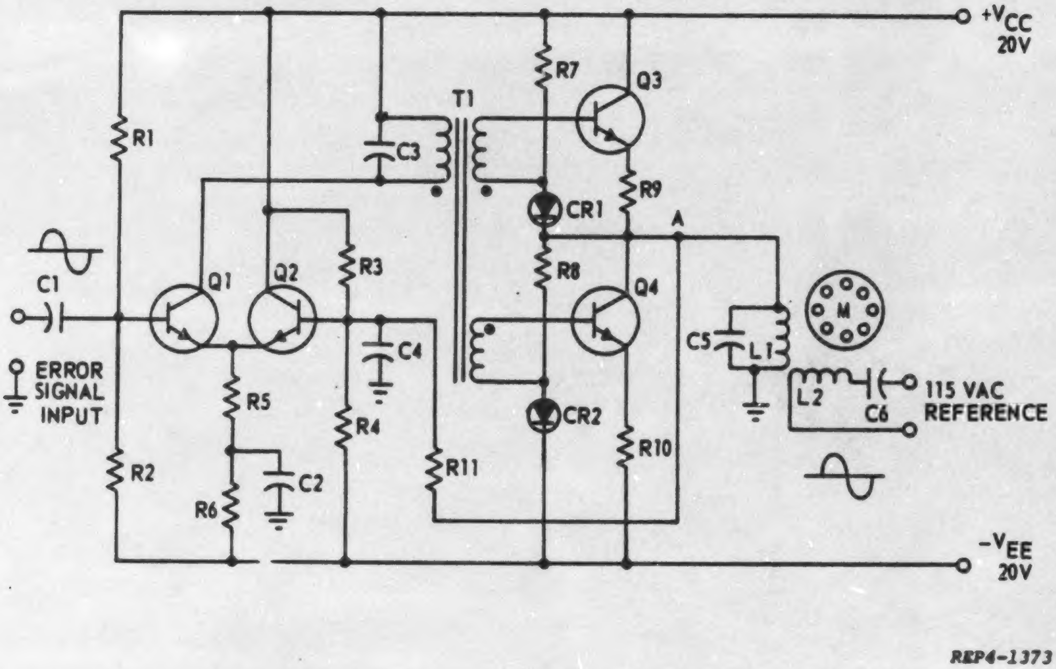

+V_{CC}
20V
R7
Q3
T1
R1
C3
R9
CR1
A
R3
Q1
Q2
R8
Q4
C1
C5
L1
M
C4
ERROR
SIGNAL
INPUT
R5
R4
L2
C6
115 VAC
REFERENCE
CR2
R10
R11
R2
C2
R6
-V_{EE}
20V
REP4-1373

Figure 41-7. Servoamplifier

Refer to figure 41-7 for questions 8, 9, and 10.

8. The feedback components for the figure are:

__a. R1 and R2.

__b. R11 and C4.

__c. R8 and R4.

__d. R10 and C5.

9. The push-pull amplifier in the figure consists of:

__a. Q3, Q4, and the secondaries of T1.

__b. Q1, Q2, and the primary of T1.

__c. Q1 and Q3.

__d. Q2 and Q4.

10. The stabilization components for Q3 and Q4 are:

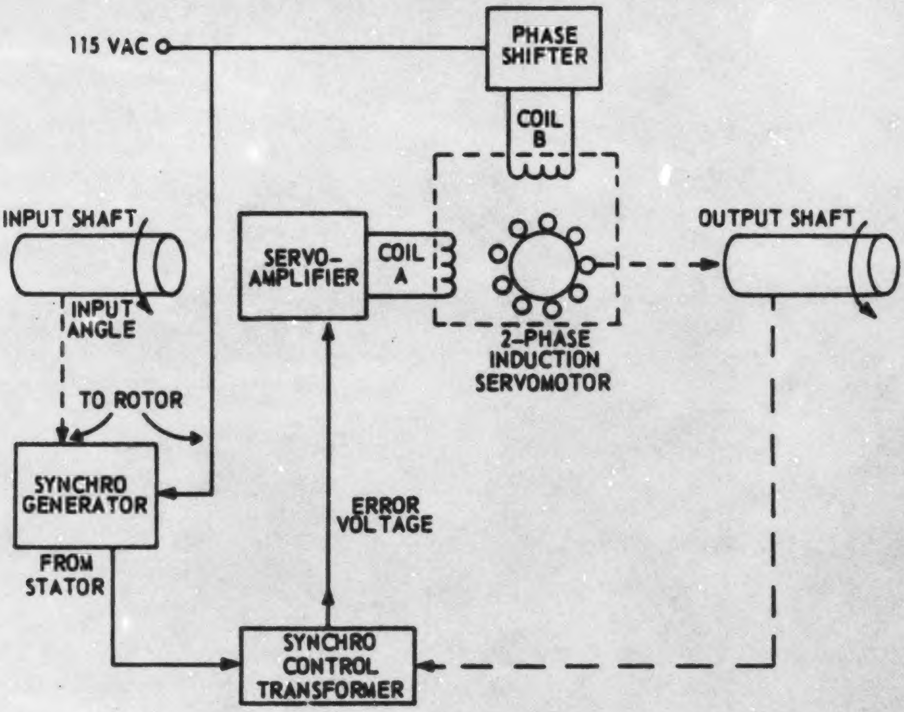
__a. R5 and R6.

__b. C2 and C4.

__c. CR1 and CR2.

__d. C5 and C6.

Refer to figure 41-8 for questions 11 through 15.


115 VAC
PHASE SHIFTER
COIL B
INPUT SHAFT
SERVO-AMPLIFIER
COIL A
OUTPUT SHAFT
INPUT ANGLE
2-PHASE INDUCTION SERVOMOTOR
TO ROTOR
SYNCHRO GENERATOR
ERROR VOLTAGE
FROM STATOR
SYNCHRO CONTROL TRANSFORMER

REP4-1374

Figure 41-8. Servomechanism

11. Select the statement that describes the operation of a servo system.

___a. A servo system utilizes synchro devices only.

___b. Servo systems produce error signals at all times.

___c. Systems using synchros produce errors which are amplified and drive motors.

___d. The rotors of the synchro devices are connected to the same 115 VAC source.

12. The voltages on coils A and B of the servomotor are:

___a. In phase.

___b. 90° out of phase.

___c. 180° out of phase.

___d. Determined by shaft alignment.

13. When the shafts are aligned, the control transformer has no:

___a. Electrical input.

___b. Mechanical input.

___c. Electrical output.

___d. Input or output.

14. The generator stators are connected to the:

__a. Control transformer stators.

__b. Induction motor stators.

__c. Input shaft.

__d. Output shaft.

15. The control transformer rotor is electrically connected to the:

__a. Output shaft.

__b. Induction motor.

__c. Servoamplifier input.

__d. Servoamplifier output.

CONFIRM YOUR ANSWERS.

ANSWERS TO A:

1. The amount of torque each system is capable of supplying. Small in synchro, large in servo.

2. False

3. a. Synchro generator
   b. Synchro motor

4. False

5. Interial damper

6. Angular position of the rotor

7. 120°

8. Transformer action

9. Rotor

10. Twice

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. 60°

2. 60°

3. 30°

4. An external mechanical device

5. True

6. No current flow

7. A to B, C to D, E to F

8. 105°

9. False

10. Reduced accuracy of entire system

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. a. Error amplifier
   b. Power amplifier

2. Speed

3. Direction

4. 90°

5. Temperature stability

6. 180°

7. Push-pull power amplifier

8. Differential amplifier

9. When no error signal is generated

10. True

11. Servo

12. Electrical

13. Output

14. False

15. Determines

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. a

2. b

3. d

4. c

5. d

6. d

7. c

8. b

9. a
10. c
11. c
12. b
13. c
14. a
15. c

HAVE YOU ANSWERED ALL THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.